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THE TEMPORAL COURSE OF THE INFLUENCE OF VISUAL STIMULATION UPON THE AUDITORY THRESHOLD[1]

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This study is concerned with the influence of a flash of light upon the audibility threshold for an accompanying tone; the principal experimental variable is the time interval between the flash of light and the tone. Several published experiments have indicated that the intensity, extensity, or discriminability of sensations may be increased by simultaneous or preceding stimulation of another sensory modality. Facilitation of several senses was reported by Urbantschitsch (**18**); of vision, by Kravkov (**12**), Zietz (**23**), Hartmann (**7**), and Thorne (**17**); of hearing, by Freund and Hofmann (**5**) and by Hartmann (**8**); of smell, by Freund (**4**). On the other hand, there is also experimental evidence for reduction of intensity of sensation upon accompanying stimulation of a different modality (Jacobsen, **10**). Similar phenomena have been observed in studies of reflex action. Both in spinal preparations (3, 16) and in the intact organism (**1**, **9**, **19**, **21**, **22**), an extra stimulus may have a facilitating or an inhibiting influence upon the magnitude of the reflex response to a given stimulus. In these studies, the attention paid to the temporal relation of the two stimuli has made possible the

[1] From the Laboratory of Psychology, Yale University. This is one of seven experimental studies of facilitation included in a project carried out in 1935–36.

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construction of plausible hypotheses as to the mechanisms underlying the two phenomena, and the consideration of motor facilitation and inhibition as instances of the more general phenomenon of motor summation (**3, 16**). An understanding of the intersensory effects might likewise be aided by studies of the influence of different time-intervals between the two stimuli. Accordingly, in the present investigation we have attempted to determine how the facilitation effect of a certain visual stimulus upon the auditory threshold varies as the time interval between visual and auditory stimulation is varied through several rather gross steps.

Procedure

For visual stimulation a 2-degree circular patch was employed. Between stimulations it was kept at a low brightness level[3] to serve as a fixation field. The stimulus consisted of raising it to a brightness of 50 apparent foot-candles for a period of 1/10th second. The sound stimulus was a 1000 d.v. tone produced in an ear-phone. Its duration was 165 milliseconds. The tone intensity in any trial was one of five intensities separated by 2-decibel steps, and so chosen that approximately half of the tones were below threshold. The level of tone intensity to be used was decided for each subject each day by a preliminary determination of the auditory threshold by the descending order of the method of limits, with visual stimulation absent. Thereafter light and tone were presented together, separated by various brief time intervals. The time intervals selected for study were: light preceding tone by 2 seconds, 1 second, and 0.5 second; light and tone simultaneous; light following tone by 0.5 second. A predetermined and counterbalanced random order of presentations of tone intensities and of intervals between light and tone was used. Each subject made 60 judgments with each of the five time intervals between onset of light and onset of tone, 60 judgments with light presented alone, 20 judgments with neither light nor tone, and 100 judgments with tone presented alone. These judgments were evenly divided over four experimental periods of about 50 minutes each; with the exception of one subject (I. C.), the periods never came on consecutive days, but beyond this there was great irregularity in the number of days that did elapse between successive periods (See Table I).

The subject, seated alone in a darkened, sound-shielded room, was given a ready signal (a low intensity click in a telephone receiver) 7.6 seconds before the onset of tone. He was instructed to fixate on the visual stimulus patch upon hearing the signal, but to set himself primarily to listen for the tone. His report was made by pressing a key if the tone had been heard. The instructions required him to delay making his report until 3.6 seconds after the tone, at which time a click signaled the time to report. This click was followed in 3.8 seconds by the ready signal for the next presentation (except

[3] Facilities for the measurement of this brightness were not available. An estimate of it may be gained from the fact that it was dimmer than the lowest attainable comparison field of the Macbeth Illuminometer (0.016 apparent foot-candles) and bright enough to be immediately visible in a dark room without the necessity of preceding dark adaptation.

for four 2-minute rest periods in the course of each experimental session). These three points of procedure should be particularly noted: that a preliminary signal placed the subject in a condition of readiness, that the report was delayed until well after the stimuli were past, and that successive stimulations were separated by only 15 seconds.

Eleven subjects, 9 graduate students and 2 instructors in psychology, took part in the experiment.[4]

Apparatus

The tone was produced in a magnetic-diaphragm-type telephone receiver (Brandes Matched Tone, + Superior). The receiver was attached over the right ear, held by a sponge rubber cap fitting around the concha so that its mouth was about ¾ inch from the meatus. The tone was not accompanied by any audible click. Other secondary cues were effectively eliminated by having the experimenter and all control apparatus outside the sound-shielded room. A beat-frequency oscillator furnished the 1000~ alternating current for the production of the tone. The intensity of the tone was controlled by an attenuator calibrated in 2-decibel steps.[5]

The light source was a 50-watt tungsten-filament lamp (operated on 115v. D.C.) enclosed in a box in the subject's room. A 1½ inch circular plate of milk glass in the otherwise lightproof box was the stimulus patch. Between stimulations, two carbon-filament lamps were in series with the stimulus lamp. Cutting these lamps out of the circuit brought the stimulus lamp to full intensity within an estimated 10 milliseconds, and throwing them in again reduced the stimulus lamp to a minimum intensity within a comparable period (estimated from photokymographic records of the flash).

Accurate control of the duration of both stimuli and of the interval between ready signal and stimuli, between stimuli and report signal, and between stimuli was obtained with a synchronous-motor timing device.

Results

a. The temporal course of the effect of the visual stimulus upon the frequency of report of tone.

Any influence of the light upon the audibility threshold would result in an increase or decrease in the frequency with which the subjects reported the tone when the light and tone were presented together in various time relationships as compared to those trials where the tone was presented alone. To exhibit the relative increases or decreases that occurred, the number of reports of hearing tone were computed for each experimental session of each subject, for each of the time-intervals between light and tone and for tone presented alone.

[4] The following persons were the subjects: Helen Howard, Martha Towne, Austin Riesen, Vincent Nowlis, Tom Gorham, Eleanor Gibson, G. R. Wendt, James Gibson, Richard Bugelski, Milford Fletcher, and Irvin Child.

[5] The electrical equipment and the sound-shielded room were the same as those used by one of the writers in a previous investigation, being part of the equipment of the Laboratory of Neurophysiology, Yale University School of Medicine (20, p. 2–4; p. 5, lines 7–24).

TABLE 1

FREQUENCY WITH WHICH INDIVIDUAL SUBJECTS REPORTED THE TONE DURING EACH SESSION, WITH THE VISUAL STIMULUS PRESENT IN VARIOUS TEMPORAL RELATIONSHIPS, OR ABSENT

(For each of the five intervals between light and tone, the number of presentations per session was 15; for tone alone, the number of presentations was 25. The total frequencies of report for each subject's four sessions are given in percentages of the number of presentations.)

Subject	Date	Number of Reports of Tone					
		Interval Between Light and Tone					Tone Alone
		−0.5″	0″	0.5″	1.0″	2.0″	
H. H.	1/ 2/36	7	9	9	8	6	9
	1/ 4/36	9	9	13	9	9	15
	1/11/36	9	10	12	11	10	17
	1/18/36	9	9	10	7	7	14
	Total (%)	57	62	73	58	53	55
M. T.	1/14/36	8	9	9	10	7	12
	1/16/36	4	4	6	4	4	5
	1/28/36	8	9	8	8	6	14
	2/ 3/36	5	6	7	5	4	7
	Total (%)	42	47	50	45	35	38
A. R.	2/25/36	4	6	8	5	4	6
	2/27/36	8	12	10	8	7	11
	2/29/36	8	7	8	8	7	7
	3/15/36	9	9	10	9	6	11
	Total (%)	50	57	60	50	40	35
V. N.	2/ 5/36	6	8	9	8	7	12
	2/ 7/36	7	10	10	9	9	15
	2/10/36	5	5	3	4	5	6
	2/14/36	9	6	10	7	7	12
	Total (%)	45	48	53	47	47	45
T. G.	2/29/36	10	12	11	11	10	16
	3/ 7/36	5	11	11	10	9	15
	3/16/36	7	5	8	6	4	6
	3/19/36	7	10	10	14	9	12
	Total (%)	48	63	67	68	53	49
E. G.	1/14/36	9	12	9	7	6	13
	1/18/36	8	11	8	10	6	14
	1/21/36	8	5	7	9	7	7
	1/23/36	3	2	6	5	4	3
	Total (%)	47	50	50	52	38	37
G. W.	12/18/35	13	13	15	14	11	23
	12/20/35	6	5	5	9	7	10
	3/ 5/36	9	9	9	10	7	11
	3/ 7/36	9	8	10	8	7	10
	Total (%)	62	58	65	68	53	54

TABLE 1 (*Continued*)

Subject	Date	Number of Reports of Tone					
		Interval Between Light and Tone					Tone Alone
		−0.5″	0″	0.5″	1.0″	2.0″	
J. G.	2/25/36	8	11	9	11	10	14
	2/27/36	10	10	8	10	5	13
	3/ 7/36	10	9	8	3	6	9
	3/25/36	10	8	8	7	6	9
	Total (%)	63	63	55	52	45	45
R. B.	12/14/35	14	12	14	13	14	21
	12/18/35	7	7	7	6	7	9
	1/20/36	11	10	9	9	6	14
	1/23/36	8	10	8	9	6	12
	Total (%)	67	65	63	62	55	56
M. F.	2/25/36	6	8	11	10	10	12
	2/29/36	7	9	9	9	7	15
	3/ 4/36	10	8	9	8	10	14
	3/26/36	12	12	13	12	13	15
	Total (%)	58	62	70	65	67	56
I. C.	3/23/36	9	9	11	9	11	16
	3/24/36	9	11	10	9	10	14
	3/25/36	3	6	7	7	8	10
	4/ 7/36	8	9	9	7	7	10
	Total (%)	48	58	62	53	60	50
Total of 11 subjects							
	1st day	95	109	115	106	96	154
	2nd day	80	99	97	93	80	136
	3rd day	88	83	88	83	76	115
	4th day	89	89	101	90	76	115
	Total	352	380	401	372	328	520
	Total (%)	53.3	57.6	60.8	56.4	49.7	47.3

In finding these totals, the presentations of light alone without tone were neglected; see section *d* below. For each subject, the frequencies of report were summed for the four sessions and converted into percentages of the number of presentations (60 per subject for each interval between light and tone, and 100 for tone alone). Similar treatment was given to the total judgments of all 11 subjects. These results are all exhibited in Table 1.

The percentage frequencies of report are also displayed graphically, for each subject separately in Fig. 1, and for the total results of 11 subjects in Fig. 2. Along the horizontal

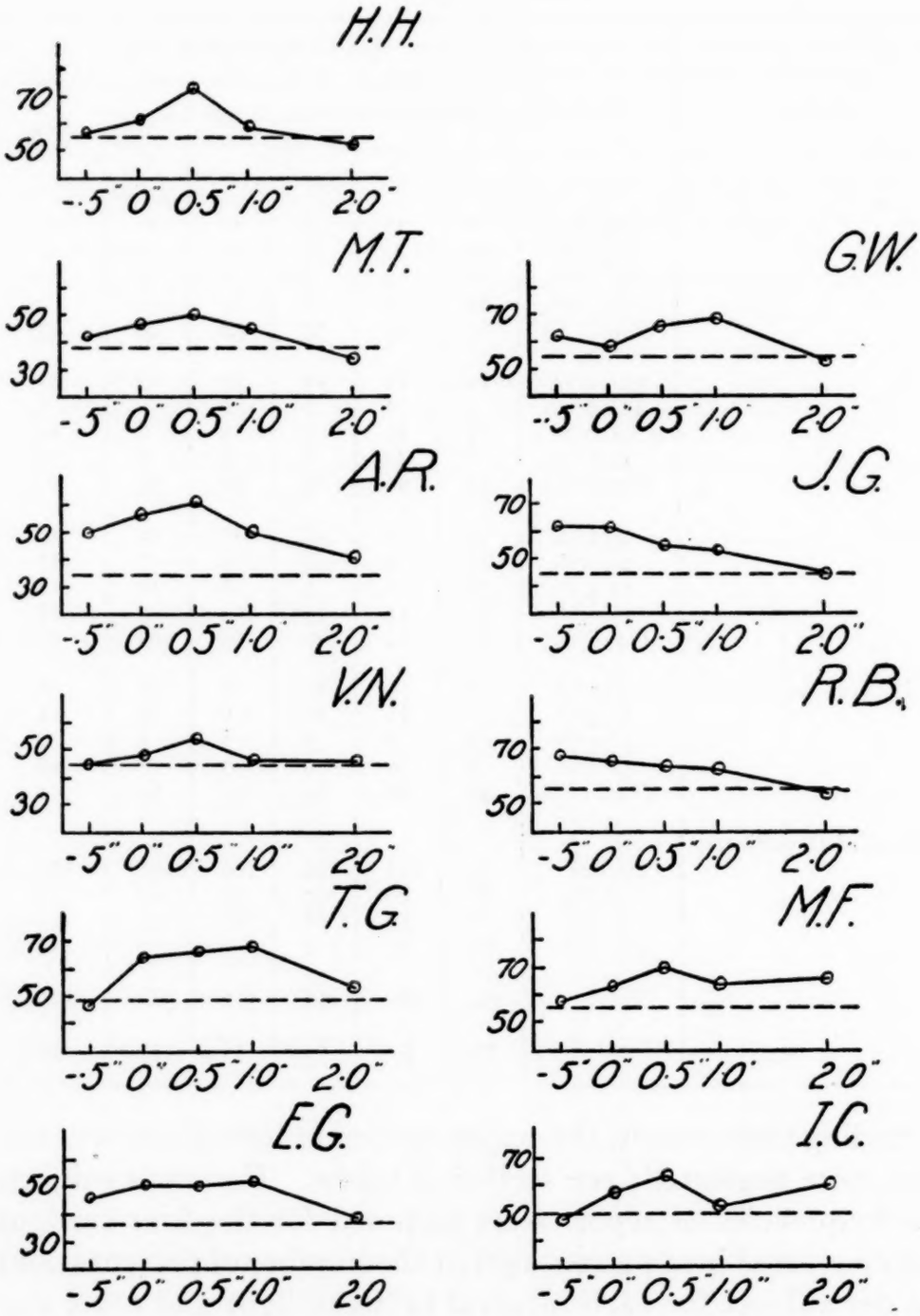

FIG. 1. Results for individual subjects, showing frequency of report of tone when the interval between light and tone is varied. Vertical coordinate: frequency of report of tone in percent of total presentations; horizontal coordinate: interval separating light and tone; broken line: frequency of reports of tone in the absence of light.

axis are shown the five time intervals used; on the vertical axis are plotted percentages of report of hearing the tone. The points have been connected with straight lines for the

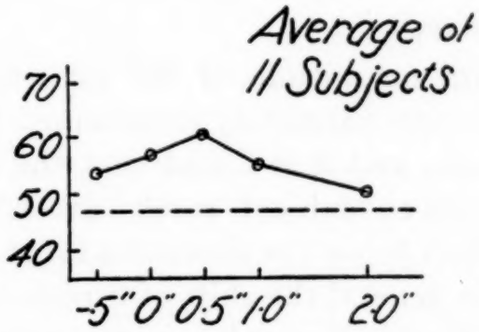

FIG. 2. Average results for 11 subjects, showing frequency of report of tone when the interval between light and tone is varied. (See legend for Figure 1.)

sake of organization, and not to suggest any given continuous function of audibility and time interval; the temporal points are too far apart to permit a reliable inference as to the shape of the curve between points. The horizontal broken line is drawn at the level of frequency of report occurring in the presentations of tone alone without light. The distance of the several plotted points above this line indicates the average degree to which the respective conditions tend to augment the frequency of report of hearing.

The results show clearly that under the conditions of this experiment threshold tones are reported more often when a flash of light occurs either simultaneously or 0.5″ or 1.0″ before, than when no light occurs. This relation is exhibited without exception in all eleven subjects, as may be seen in the separate charts for the individual subjects, Fig. 1. In general, the optimal time-interval, of those employed, is 0.5″, since 6 of the 11 subjects agree with the average result in showing at that point the greatest frequency of report. When a light follows the tone by 0.5,″ there is evidence of an increased frequency of report in some subjects; 2 subjects (J. G., R. B.) show a maximum frequency with this interval, though with some subjects there is no increase at all. When, on the other hand, the light precedes the tone by 2.0″, 5 subjects show at least as low a frequency of report as when the

tone is presented alone, and the average results for all subjects indicate very little deviation from the results for tone alone.[6]

b. The magnitude of the effect of the visual stimulus upon the auditory threshold.

The maximum magnitude of the influence found is not great. It can be approximately determined by inspection of the daily protocols, and it is found that the conditions most favorable for a given subject rarely extend the audibility more than 2 decibels below the threshold for the least favorable conditions, and in general the shift of threshold is not as great as 2 decibels. This effect may be characterized as very small.

c. Variations in the results during the course of the experiment.

For each subject, the results varied between successive days of experimentation; because of the small number of determinations on each point per day, these changes cannot be regarded as reliable. It was possible, however, to sum the results of all subjects for each of the four experimental sessions, to see whether there was any general tendency for the observed effects to change with experience in the situation.

[6] Critical ratios were computed as follows: For each condition of presentation, the percentage frequency of report of tone by each subject was considered as a score for that subject, and the σ of the distribution of 11 scores was computed. The σ of the mean score was then computed by the formula $\sigma_M = \sqrt{\frac{\sigma^2}{N-2}}$ (Guilford, **6**, p. 51). The σ of the difference between mean scores for any two conditions of presentation was found by the formula $\sigma_{diff.} = \sqrt{\sigma_{M_1}^2 + \sigma_{M_2}^2}$. (Although there was a high degree of correlation between the mean scores for any two conditions, this correlation was entirely or mostly due to the irrelevant fact that the average intensity level of auditory stimulation varied between subjects but was a constant for the several conditions for each subject; the correlation was therefore disregarded in the formula for $\sigma_{diff.}$.) The deviations of the other results from results with tone alone yielded the following critical ratios: interval −0.5″, C.R. = 1.7; 0″, C.R. = 3.2; 0.5″, C.R. = 3.8; 1.0″, C.R. = 2.5; 2.0″, C.R. = 0.5. This indicates virtual certainty of true deviation for the intervals 0″ and 0.5″, fair probability of true deviation for the intervals 1.0″ and −0.5″ (99 and 96 chances in 100, respectively, of a true deviation), and nearly even chances (69 in 100) of a true deviation for the interval 2.0″. The reliability of the finding that 0.5″ was the optimum time interval is not very great. The differences between the frequency of report of tone with this interval and with the intervals 0″ and 1.0″, have critical ratios, respectively, of only 1.0 and 1.2, although the corresponding critical ratios when the −0.5″ and 2.0″ intervals are compared with the 0.5″, reach 2.0 and 2.6 respectively.

The results are plotted graphically in Fig. 3. The first day gave on the whole results most nearly like the average results for all days. The only change of very significant magnitude during the course of the experiment is the change in frequency

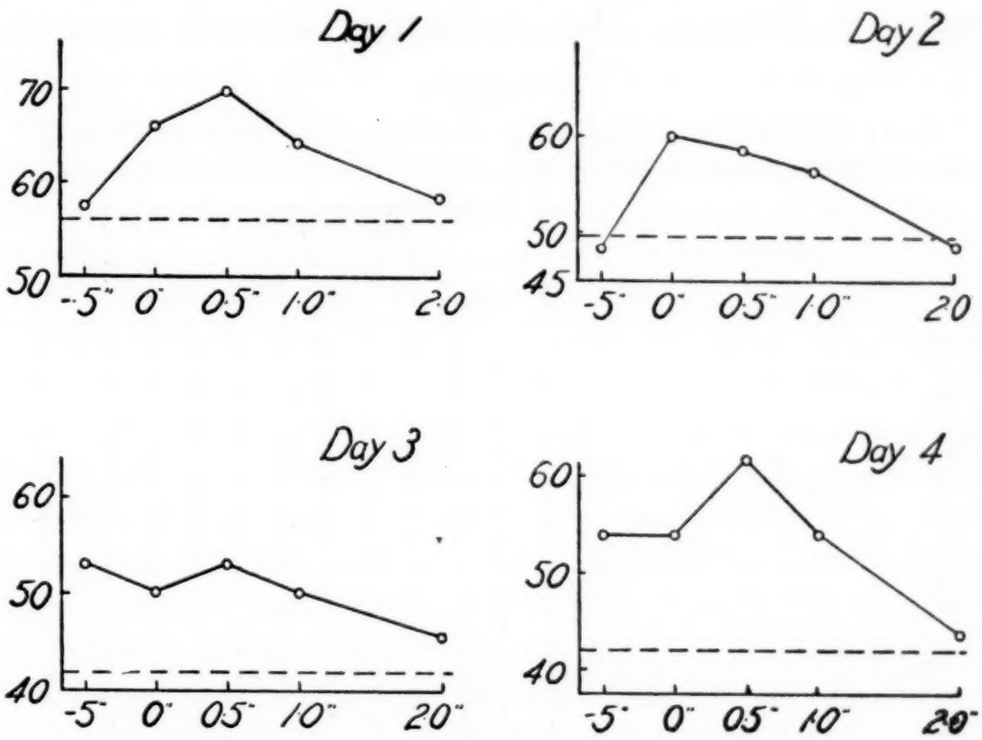

FIG. 3. Average results for 11 subjects, showing frequency of report of tone for each condition of stimulation during successive sessions of the experiment. (See legend for Figure 1.)

of report with light following tone by half a second. Eight of the 11 subjects show more facilitation under these conditions in the last two sessions taken together than in the first two sessions. This difference is in some cases quite large; and the three subjects where the difference is in the opposite direction show only a small difference. So there are probably factors other than chance variation making for this shift.

d. Reports of hearing when no tone was present.

If the effect of the visual stimulus had been primarily to cause the subjects to report a tone when they did not actually hear a tone, the results would not signify a genuine shift in the audibility threshold. To check on this possibility, the tone

was omitted in 80 presentations with each subject. In 20 of these instances, the light was also omitted; in the others, the light appeared 12 times in each temporal position with respect to the warning click signal and to the time when the tone would normally have occurred. The results are presented in Table 2. Most subjects occasionally reported a

TABLE 2

TOTAL FREQUENCIES OF REPORT OF TONE WHEN NO TONE WAS PRESENT

Subject	Interval Between Light and Normal Position of Tone					No Light
	−0.5″	0″	0.5″	1.0″	2.0″	
H. H.	0	1	0	1	0	0
M. T.	0	0	0	0	0	0
A. R.	1	0	0	0	1	0
V. N.	1	0	0	1	0	0
T. G.	0	0	0	0	1	0
E. G.	0	0	1	0	1	0
G. W.	2	0	1	1	0	1
J. G.	0	0	0	0	0	0
R. B.	0	1	1	0	1	2
M. F.	0	0	0	0	0	0
I. C.	1	2	1	0	2	1
Total	5	4	4	3	6	4
%	3.8	3.0	3.0	2.3	4.5	1.8

tone when no tone was present; three subjects never did so. From the total results, it appears probable that the tendency to report in the absence of tone is greater when the visual stimulus is given than when it is not, though this finding could not be regarded as at all reliable. The relative frequency of report with the several temporal positions of the visual stimulus is different from the corresponding results when the tone was actually presented, but again the number of instances is too small to permit reliable comparisons.

There was no conspicuous tendency for these false reports to increase in number as the experiment progressed. Six occurred during the first of the subjects' four sessions, five during the second session, seven during the third, and eight during the fourth.

Discussion

The small magnitude of the effect found in this study could lead to one of three interpretations. It might be taken to indicate that the facilitating influence of a visual stimulus upon the audibility threshold is indeed slight and is therefore a phenomenon of little significance in the normal functioning of the individual. On the other hand, the small magnitude of the effect might be a function of two elements in the experimental conditions. First, by using a ready signal we put our subjects in a condition of nearly maximum effectiveness, and any added influence of the light stimulus could therefore have been only slight. A useful extension of this research problem would be its repetition under conditions where no warning signal was used. Second, Kravkov reported (**12**) that the facilitating effect of an extra stimulus lasts for several minutes, dying out gradually. If this is so, our presentations without light were really subject to the influence of the last several stimulations with light. The control presentations would then represent only the level of perceptibility at a certain stage in the decay of the facilitating effect, and not the level of perceptibility in the complete absence of facilitation; the difference in frequency of report between experimental and control presentations would in this case be expected to be very small. In any case, however, it seems worthwhile to consider what mechanisms might be responsible for the observed effect. The possible interpretations may be considered under four heads:

(1) The results as an artifact of the method of report.
(2) The results as due to peripheral effects of the auxiliary stimulus.
(3) The results as due to the summation of excitatory processes in the central nervous system.
(4) The results as due to higher-order processes of attention and judgment.

(*1*) *The results as an artifact of the method of report.*

In planning the experiment, we considered the possibility that if the subject was uncertain whether he had heard the

tone, the extra stimulation provided by the light might facilitate the tendency to press the report-key, so that our results would be due to direct facilitation of the reporting response rather than to sensory summation. In an attempt to minimize this possibility, the subject was required to delay his report until a signal was given 3.6 seconds after the presentation of the tone. Introspective comments made by the subjects give no hint that this device failed to accomplish its purpose. Nevertheless, the possibility of a sort of motor facilitation cannot be said to have been thus entirely eliminated. It was to check on its occurrence that a number of presentations of light alone without tone were introduced. It was found that in these presentations the frequency of report was less than 5 percent (see Table 2). If it be assumed that the just-below-threshold tones (approximately 50 percent of all the tones given) were reported (without being heard) in this same proportion (5 percent), then the resulting augmentation of frequency of report would be only 2.5 percent, whereas the observed augmentation was for the optimal time interval 13 percent. Clearly, then, the results cannot be in any large part due to a summation of the visual excitation with the general response-tendency set up by the situation.

Another possibility is that since the subject frequently responded to the paired stimulations by pressing the key, he might finally come by simple conditioning to press the key when only the visual part of the stimulus-pair occurred. The fact that the light following the tone by half a second showed on the average no augmenting effect on the frequency of report during the first two days of experimenting, but did show an effect during the last two days of experimenting, might suggest such an interpretation for at least that particular condition. The effect of the light when it precedes the tone by 1.0″ and by 2.0″ shows less reliably a similar tendency to increase during the course of the experiment (see Fig. 3). The check which eliminated a simple motor effect of the light from consideration as a major determinant of the results applies, however, equally well to the possibility of a conditioning effect. Furthermore, the fact that reports of

hearing when no tone was presented did not conspicuously increase from one session to another weighs against the possibility of a conditioning factor. We may safely conclude that the results of this experiment cannot be interpreted as a mere artifact of the method of report.

(*2*) *The results as due to peripheral effects of the auxiliary stimulus.*

The more careful studies of the facilitating influence of non-visual stimuli upon vision have taken precautions to ensure that facilitation does not occur by way of the extra stimulus' serving to improve the receptive adjustment of the eye. Hartmann (**7**) and Serrat and Karwoski (**15**) used an artificial pupil and provided a fixation point or field before the onset of the visual stimulus. In studying influences upon the auditory threshold, however, there is a possible peripheral variable which it would be very difficult to control, for it may be that the muscles of the middle ear, their innervation changing as a consequence of the flash of light, operate to affect the auditory threshold. So far as present evidence goes, it appears that the *tensor tympani* and *stapedius* muscles act only in a manner to reduce the amplitude of transmitted sounds by going into sustained contraction when sounds reach high intensities (**11**, **13**, **14**). There is also evidence that these responses may be conditioned, occurring in an anticipatory fashion before the onset of sound (**13**). For these muscles to function as listening muscles, operating so as to improve sound transmission, would presumably require that they be in continuous slight tonic contraction, and that this be subject to inhibition when listening takes place. There seems to be no experimental evidence for any such listening function of the middle ear muscles and the otologists referred to do not believe they have this function; however, their observations have not conclusively disproved a listening function.

(*3*) *The results as due to the summation of excitatory processes in the central nervous system.*

It is assumed by some investigators that the most probable explanation of intersensory facilitation lies in a theory of

irradiation of cortical excitation. Hartmann (**8**, p. 822), for example, suggests "that the neural activity originating in the occipital lobe spreads to other receptor areas of the cortex (particularly the temporal section) and by subexciting those regions before or during specific stimulation increases the phenomenal intensity of the auditory experiences." Kravkov (**12**) uses a similar explanation. On the other hand, there is a lack of real evidence for this theory, and Serrat and Karwoski (**15**) doubt that an explanation of the experimental results in terms of a central effect is the most feasible one. We wish to point out that the temporal relations found in the present experiment are in general consonant with an interpretation in terms of central nervous processes.

In that we find maximum facilitation when the interval between the two stimuli is relatively short, and a decreasing amount of facilitation as the interval increases beyond a certain point, our findings resemble those of studies of motor summation. In considering the magnitude of the effective time intervals, it is important to distinguish two general types of motor summation. The first type of motor summation involves the summation of two discrete reflexes operating on the same effector but stimulated from different receptors. Here, the maximum interval that will permit a facilitating effect of the one stimulus upon the response to the other is considerably shorter than the intervals that we have found to produce sensory facilitation. Hilgard (**9**), for example, in studying the effect of a visual stimulus upon the magnitude of the lid reflex to sound, found that the interval had to be less than 75 milliseconds for facilitation to occur. Wendt (**19**), in studying the effect of a contralateral blow to the patellar tendon upon the response to an ipsilateral blow, found maximum facilitation when the contralateral blow preceded the ipsilateral by 150 milliseconds, and there was some evidence of facilitation when the interval was as great as 300 milliseconds; with an interval of 500 milliseconds inhibition set in. In both these studies the facilitation was interpreted as due to the convergence of the two sets of impulses upon a final common path, and the intervals permitting facilitation were

interpreted as a function of the relative latencies and recruitment periods of the two converging excitations.

One need not conclude, however, that intersensory summation would be due to irradiated excitations showing so little temporal dispersion. Kravkov and Hartmann explain it in terms of a more general irradiation of central excitatory processes. It should therefore be more akin to a second type of motor summation that occurs when a stimulus which does not have any special connection with a given effector influences a reflex response of that effector to some other stimulus. In this type of motor summation the intervals which permit facilitation are somewhat greater than in the first type. Bowditch and Warren (1) studied the time-relationships of the summating influences of a variety of stimuli upon the knee-jerk. Though with some extra stimuli there was only inhibition, and with some the facilitating effect was present only if the interval was as short as 200 milliseconds or 300 milliseconds, yet the facilitating intervals are in general longer than in Wendt's work; with voluntary muscle contraction as the extra stimulus, facilitation occurs with an interval as great as 600 milliseconds in some subjects, and over 400 milliseconds for the average results of all subjects. In the present experiment, there was clear evidence of facilitation with an interval of 1.0 second. So it appears that the phenomenon observed here is dependent upon some process which has a longer duration than does the process responsible for the positive phase of motor summation.

If the processes involved here are closely related to those involved in motor summation, it might be expected that with time intervals longer than 2.0 seconds (or possibly with intervals between 1.0 and 2.0 seconds), there would be a diminution in frequency of report of tone below the frequency of report when tone is presented alone. For in motor summation studies, it has almost always been found that when the interval between stimuli is increased beyond the maximum interval that permits facilitation, an inhibitory effect is found; indeed, the magnitude of the inhibitory effect is often greater than that of the facilitating effect. This provides an interest-

ing suggestion for further experimentation, but the present experiment provides no evidence that inhibition would or would not occur.

The most striking difference between our results and those of studies on motor summation lies in the fact that we found augmentation even where the extra, visual stimulus followed the primary, auditory stimulus by 0.5 second. It is unlikely that the slightly sub-liminal auditory excitation would persist with sufficient strength for half a second so that an extra stimulus could then bring it to the level of perceptibility. It may be that this finding is indicative of the conclusion that the phenomena reported here are dependent upon more complex conditions than the simple summartion of two excitatory processes in the central nervous system. However, it should be remembered that with light following tone, facilitation occurred, in the total results, only in the last two of the four experimental sessions; this may well indicate that this particular finding was due to different factors from those producing the other results which were consistent throughout the experiment.

In general, then, our results are probably consonant with an interpretation in terms of the summation of irradiated excitations in the central nervous system, the interpretation most often proposed of the alleged phenomena of intersensory summation.

(4) *The results as due to higher-order processes of judgment and attention.*

Introspective reports of the subjects indicated that the visual stimulus sometimes acted to modify the state of attention. For example, it was reported that the light served to pep one up or to make one more alert or more interested. Our results are not on the whole inconsistent with an interpretation in terms of relative degrees of alertness produced by the different stimulus-situations. Facilitation where the light follows the sound would be difficult to interpret in this way, but it was a questionable finding. That we found the optimum interval to be half a second, whereas Breitweiser (2)

found that the optimum interval for a signal in a reaction-time experiment was over one second, does not preclude this interpretation, for the light could have served here only as an auxiliary signal when the subject was already in a state of preparedness. To say that the results were due to variations in the degree of alertness is not inconsistent with the hypothesis of central summation, as Hartmann points out (**8**). But 'alertness' does suggest a complex of additional factors, such as the peripheral factors previously considered, and other muscular responses which provide secondary summating stimuli; thus it would be indicated that the phenomena of intersensory facilitation may involve the commonly assumed irradiated effect of the auxiliary stimulus but also involve a number of other contributing factors.

Besides variations in alertness, the subjects' introspective reports also indicated the presence of a number of judgmental variables. Some subjects reported that during the course of the experiment they sometimes used the presence or the particular temporal position of the light as an aid in judging whether a doubtful tone had been a real tone or had been an hallucinatory experience. Some of these secondary criteria, if used constantly enough and by enough subjects, could have been responsible for a large part of our results; but it is more likely that they would be so variable as to obscure the differential results for the five time-intervals. So far as could be casually noticed, there was no relation between a subject's asserted criteria and his actual recorded judgments. It would be desirable, however, to minimize this possibility either by using highly trained subjects or by using naive subjects for so short a period that they would have no opportunity to develop secondary criteria of judgment.

Summary and Conclusions

This study concerned the influence of a flash of light upon the audibility threshold for an accompanying tone. When the light and tone were simultaneous, or when the light preceded the tone by half a second or one second, there was a highly reliable increase, observed in all subjects, in the

frequency with which near-threshold tones were reported as heard; the maximum effect was found when the light preceded by half a second. When the light followed the tone by half a second, the facilitating effect was absent, for the average of the 11 subjects' results, in the first two experimental days but reliably present in the last two days. When the light preceded the tone by two seconds there was no consistent facilitating effect. In all experimental conditions, the maximum facilitating effect was of small magnitude.

The study was undertaken in an attempt to determine temporal relations in the alleged phenomena of intersensory summation in the central nervous system. It is shown that our findings are not inconsistent with the temporal relations which might be expected if intersensory summation is produced primarily by central processes similar to those operative in motor summation. It is pointed out, however, that we have not succeeded in isolating central irradiation of neural impulses as the only possible mechanism responsible for our results; our results may have been in whole or in part determined by the action of the middle ear in response to the visual stimulus, or by complex phenomena of attention and judgment.

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THE CHANGE WITH TIME OF A THORNDIKIAN RESPONSE IN THE RAT[1]

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Recently there has been an increasing tendency to identify the Thorndikian (rewarded) response with the Pavlovian conditioned response (**2**, **5**, **9**, **14**). Although the two types of reaction exhibit formal differences (**5**, **14**), if experimental test reveals a functional similarity, they may, at least tentatively, be subsumed under one heading. Skinner (**13**) has reported that a Thorndikian response exhibits acquisition, extinction, and spontaneous recovery of a kind also found in conditioning, and the writer (**18**) has determined some of the quantitative relationships existing between these three characteristic phenomena. Of the many variables in terms of which a further comparison could be made, retention was chosen as the next to be examined.

A number of studies, summarized by Razran (**10**, **11**) and Hilgard (**2**), have shown that the conditioned response is retained in various animals and man for from one month to two years, the longest interval measured. Hilgard and Campbell (**3**), working with the conditioned eye-lid response in man, found a rise in the retention curve from one day to four weeks, when the strength of the excitatory tendency was measured by number of responses during extinction. They also found a rise in strength from one day to eight weeks when speed of reconditioning was the index of retention. Thorndike (**17**, p. 110) has stated that other sorts of learning, including learning by reward, differ from conditioning in

[1] The writer is indebted to Professor Clark L. Hull, in whose laboratory this investigation was performed, for valuable suggestions and criticism during the performance of the experiment.

This is the second of a series of studies presented as a dissertation to the faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology.

that the conditioned response becomes stronger from disuse, while other sorts become weaker. It is the purpose of the present experiment to discover what changes in strength have occurred in a single Thorndikian response, of the sort found in problem-box learning, at one day and at fifteen days after training. A comparison will also be made between a response given forty training trials and one given only ten.

Apparatus and Procedure

Thirty-nine male rats of the Experimental Colony strain from the Wistar Institute were used as subjects. At the beginning of its training each was approximately 95 days old and had not been used in any previous experiment.

The rats were run in two sets, one of 19 and one of 20, the procedure with the second being exactly the same as with the first. Each set was separated into four groups and, as closely as was possible, the litter-mates were divided equally among them. Groups 1 and 2 were given forty reinforced (rewarded) training trails and then underwent experimental extinction after one day and fifteen days respectively. Groups 3 and 4 were given ten reinforced trials and then, like the first two groups, were extinguished, one after one day and the other after fifteen days. Following this first critical test, another extinction was given to all the groups twenty-four hours later. This was done in order to determine whether the amount of spontaneous recovery was a function of the number of previous non-reinforced responses, as was found in a previous experiment (18). A third extinction series was then given to all groups. This one was twenty minutes after the second, in order to see if recovery would occur in that short interval.

The two sound-shielded boxes and the procedure used in this experiment have been more fully described in an earlier article (18). The experimental boxes were essentially similar to those designed by Skinner (12), with the exception that in the present situation each box had a double-paned observation window through which the experimenter could watch the rats. At one end of the relatively large animal-chamber was a panel, near and parallel to which was placed a short horizontal bar. When the rat exerted a pressure of fifteen grams on the bar, it moved downward $\frac{1}{2}''$, a click occurred, and electrical contact was made, and a pellet of food weighing 1/25 gram was deposited in the food-tray beneath the bar. A depression of the bar followed by a pellet of food constituted one reinforcement. During extinction no food-pellet was received after the response to the bar. The process of extinction was considered complete when a period of twenty minutes had elapsed during which there was no response to the bar. All depressions of the bar were recorded on a polygraph by an electromagnetic marker.

During a four-day habituation period preceding the training trials each rat was placed in an experimental box daily with no bar present. It was allowed to explore for an hour the first day and for one-half hour on each of the three succeeding days. On the morning following these habituation periods the rat was again placed in the experimental box and training began.

Acquisition-Time and Extinction

The rats receiving forty training trials were found to require less and less time for each successive group of ten reinforcements. The curve is negatively accelerated as shown in Fig. 1, which is in agreement with the results previously

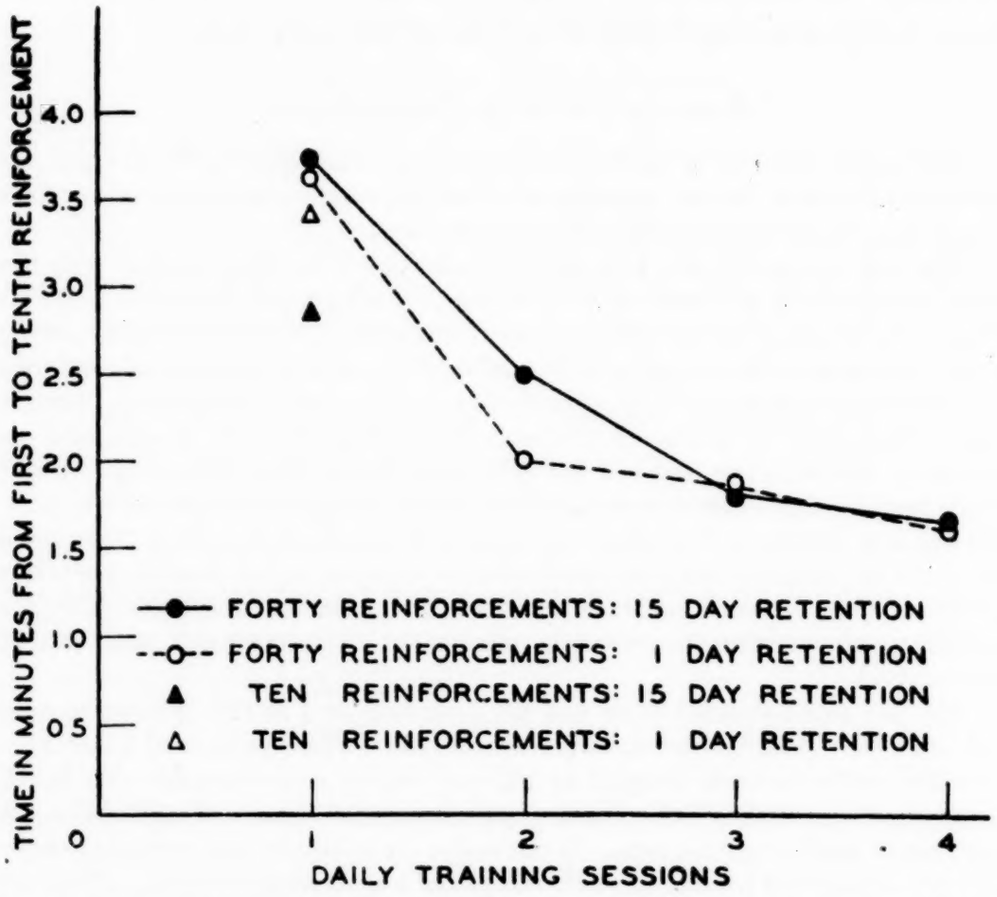

FIG. 1. Time necessary for ten reinforcements on each of four successive days of training.

The forty-reinforcement rats were allowed ten rewarded trials a day for four days. The mean times for these responses are shown by the solid and open circles. The triangles indicate the times for the rewarded responses of the two ten-reinforcement groups. Each point in the above graph represents the mean for ten rats, except for the solid dots which are determined by the averages for nine animals.

reported (**18**). However, the high negative rank-order correlation ($-.77 \pm .14$) between acquisition-time and number of extinction-responses, found when extinction followed immediately after the fortieth reinforcement, was not confirmed in this experiment. When an interval of 24 hours was interposed between training and extinction, the rho became

$+ .69 \pm .18$. Thus the rats which waited a longer time between successive reinforced trials gave a greater number of extinction responses. This suggests the effect of distributed practice as contrasted with massed in which there is the possibility of the presence of 'inhibition of conditioning.' However, it will be remembered that in the present experiment the external situation is constant and the rat determines the intervals between successive responses. Presumably, if any sort of inhibitory effect were present during training, the rat's rate of responding would decrease. This, in turn, would diminish the generation of inhibition and there would be an equilibrium established in which the formation of the inhibition would be balanced by its dissipation. It therefore seems unlikely that this positive correlation is the result of dissipation of the inhibition of conditioning.

Statistical analysis again showed the number of extinction-responses to be a more reliable index of original reinforcement than the time for extinction or the rate of responding during the extinctive process.

Retention of Differentially Reinforced Tendencies

With both the ten- and forty-reinforcement groups the animals undergoing extinction 15 days after training made a greater number of extinction-responses than those extinguished 1 day after training. The mean values at the various points together with their reliabilities are shown in Table I

TABLE I

Retention of Differentially Reinforced Tendencies as Measured by Their Resistance to Extinction

Experimental Groups	At 1-day Retention		At 15-day Retention		$\sigma_{Diff.}$	$\frac{Diff.}{\sigma_{Diff.}}$
	Mean Responses	σ_M	Mean Responses	σ_M		
10-reinforcements....	30.1	5.77	39.9	10.28	11.70	0.84
40-reinforcements....	40.9	4.14	70.6	7.42	8.50	3.49
$\sigma_{Diff.}$.....	7.10		12.60			
$\frac{Diff.}{\sigma_{Diff.}}$.....	1.52		2.44			

With one exception each mean represents the data for ten rats. The 40-reinforcement, 1-day retention group contains only nine.

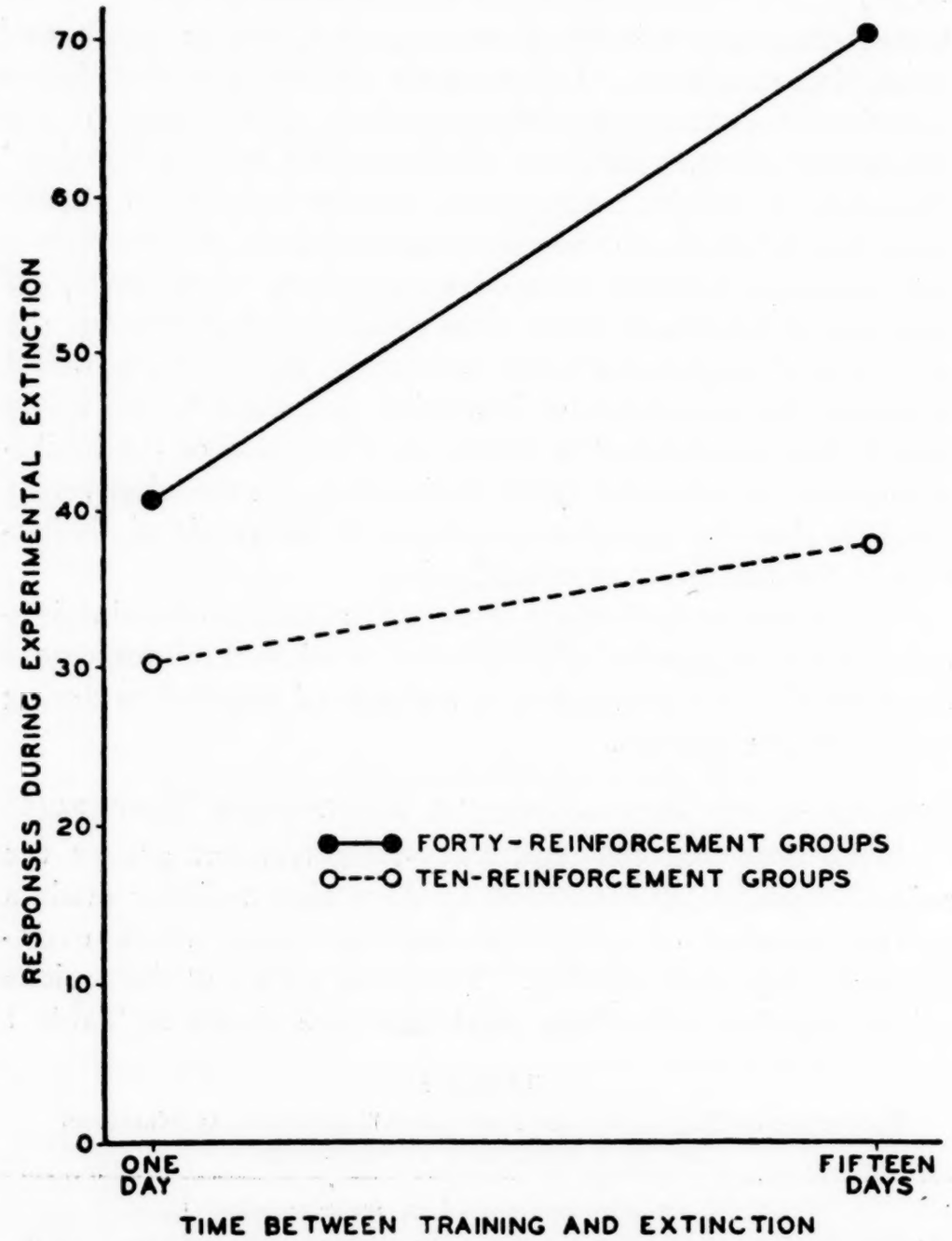

FIG. 2. Retention as measured by resistance to extinction at one day and fifteen days after training.

Each point represents the mean for a separate group of animals. During the retention-periods the rats remained in their home-cages and received no further training. The forty-reinforcement, one-day retention group contains nine rats. The other three groups have ten each.

and Fig. 2. The rise in strength of the stronger tendency is disproportionately greater than that of the weaker, with the former showing a difference that is statistically reliable.[2]

This rise in the retention curve of a Thorndikian response is paralleled by similar findings reported by Hilgard and Campbell (3) for the conditioned eye-lid response. Following the training trials, they tested different groups of subjects after 1 day, 1 week, 4 weeks, 8 weeks, and 20 weeks. The number of responses during an extinction series was found to increase up to 4 weeks and then to fall off through 8 weeks and 20 weeks. Their data and the results of this experiment are closely analogous in the direction of change of strength of a tendency over temporal intervals, although they are not comparable in terms of number of reinforced trials given.[3]

In investigating this rise for the conditioned response, Hilgard and Campbell found that during the retention-interval the unconditioned responses to light and air-puff had become stronger through a loss of habituation. However, the size of the increase in these unconditioned responses was not large enough to account for all of the change in strength of the conditioned reactions. They suggest another factor that would at least prevent a drop in the retention curve. This was that there had been no opportunity for the various component stimuli in the experimental situation to become attached to new responses.[4]

It seems likely that similar factors were present in this experiment. Before the actual training, the rats went through a series of four orientation periods, during which

[2] This difference was evident when the first four groups of rats, making up the first set of 19 animals, were run. It was principally because of this unexpected increase in the resistance to extinction after 15 days that the entire experiment was repeated on a second set of 20 rats. The second experiment confirmed the first, and the results were pooled.

[3] Another difference is that in the rewarded response used in this experiment the ratio of extinction-responses to reinforcements is much greater than in the conditioned response. Hilgard and Campbell remark that "10 extinguishing trials have undone temporarily the work of some 90 reinforcements" (3, p. 233).

[4] Guthrie (1) has said that 'forgetting' of a learned stimulus-response relationship probably involves the acquisition of new responses to the original stimulus.

This aspect of response decrement has also been pointed out for verbal material by Jenkins and Dallenbach (7) and by McGeoch (8).

they became habituated to being taken from their home-cage and placed in the experimental box. The first time a rat was placed in the box there was a great deal of excited exploratory behavior. This decreased during successive orientation periods until the rat seemed quite unafraid of the experimental situation. After training, the rat stayed in his home-cage, which was quite unlike its surroundings during reinforcement, until the day of the retention test. There had been little chance for experimental cues to become attached to new responses, and there was the possibility at least that the rat had lost his habituation to the box.[5] If through this loss of habituation the rat again found the box a 'new' situation, there would result the heightened excitability which probably increases the resistance to extinction.[6]

An experiment to test this hypothesis could easily be performed with the present form of experimental setup. During a 15-day retention-period after forty reinforcements, a test group of half the rats could be placed in the experimental box several times without access to any foodgetting mechanism. It seems probable that the number of extinction responses made by the test group at the end of the interval would be materially less than for the control group. Such an experiment would have interesting implications for retention in both Thorndikian and conditioned response learning, and might throw some light on the theoretical relationship between motor and verbal retention.

Spontaneous Recovery

The first extinction, described above, which was a test for retention, was followed for all four groups of rats by another extinction 24 hours later. Although all differences are greatly reduced, the trend of the retention curve is still upward from the one-day to the fifteen-day interval. However, the slope of the lines in Fig. 3, where these values are plotted, is much less than the slope at the first extinction

[5] Humphrey (6) has shown that habituation is dissipated in much the manner characteristic of Pavlovian inhibition.

[6] Switzer (16) found that a caffeine-produced excitability increased the resistance to extinction of the conditioned galvanic skin response.

(shown in Fig. 2). This tends to corroborate the hypothesis presented in the previous section, by which the greater loss of habituation after the longer retention-interval was one of the factors producing the increased resistance to extinction at

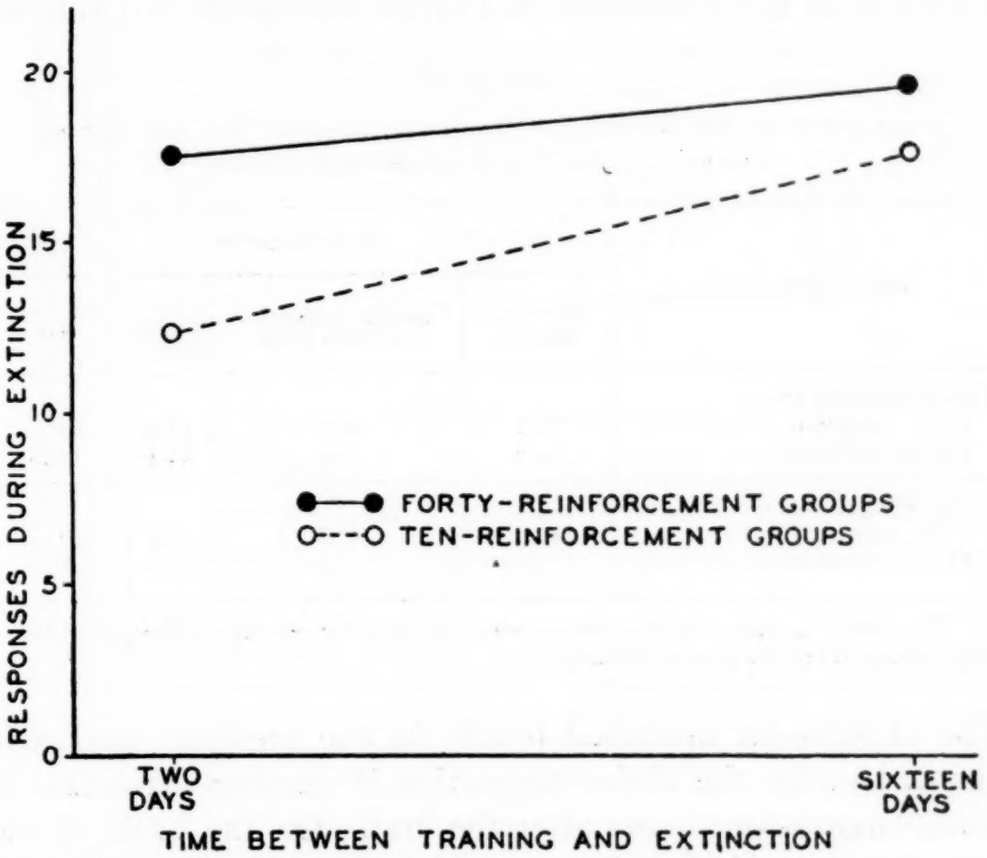

FIG. 3. Spontaneous recovery, measured by a second extinction twenty-four hours after the first.

The first extinction (shown in Fig. 2) tested the retention of the learned response for all four experimental groups. The second, the results of which are shown above, indicates the amount of spontaneous recovery that occurred during the twenty-four hours following the first extinction. Each of the points represents the mean for ten rats, except for the forty-reinforcement group extinguished for the second time two days after training. This one contains nine.

that point. It seems probable that the loss of habituation is responsible for part of the increased strength, and that during the first extinction most of the habituation to the box-situation is regained. Then the spontaneous-recovery test after the extinction at fifteen days should show a greater proportional decrease in number of responses than the comparable test following the extinction at one day after

training. This *disproportionate* decrease is found to hold for the forty-reinforcement group only, although the *absolute* value of the decrease is greater at fifteen days than at one day for both the ten and forty-reinforcement rats. The mean values with the differences and ratios are shown in Table II.

TABLE II

COMPARISON OF THE NUMBERS OF RESPONSES AT THE FIRST AND SECOND EXTINCTIONS FOR ALL EXPERIMENTAL GROUPS

Experimental Group	Mean Responses			
	First Extinction	Second Extinction 24 Hours Later	1st Minus 2nd	% 2nd is of 1st
Ten reinforcements				
1-day retention	30.1	12.6	17.5	42%
15-day retention	39.9	17.5	22.4	43%
Forty reinforcements				
1-day retention	40.9	17.8	23.1	43%
15-day retention	70.6	19.7	50.9	28%

The means in each case but one represent the data for ten rats. The 40-reinforcement, 1-day retention group contains nine.

The experiment described briefly in the previous section is also a test for the above suggestion if another extinction is given twenty-four hours after the first. On the basis of the foregoing hypothesis, the rats which had been placed in the experimental situation several times during the 15-day retention interval would be expected *not* to show the disproportionate decrease in number of responses from the first extinction to the second.

Another and final test for spontaneous recovery was made twenty minutes after the end of the second extinction. The rats were kept in a small cage in the experimental room during the twenty minutes between the second and third extinction and then were put into the experimental box exactly as they had been before. The results are plotted in Fig. 4. Although Skinner (**15**) has reported a failure to obtain 'disinhibition' under circumstances comparable to the present, there still remains the possibility that some of the responses were a

result of some disinhibiting change in the external situation. No test was made for this effect. If it is assumed that the responses made during this third extinction were the result of spontaneous recovery, then a comparison of the third and

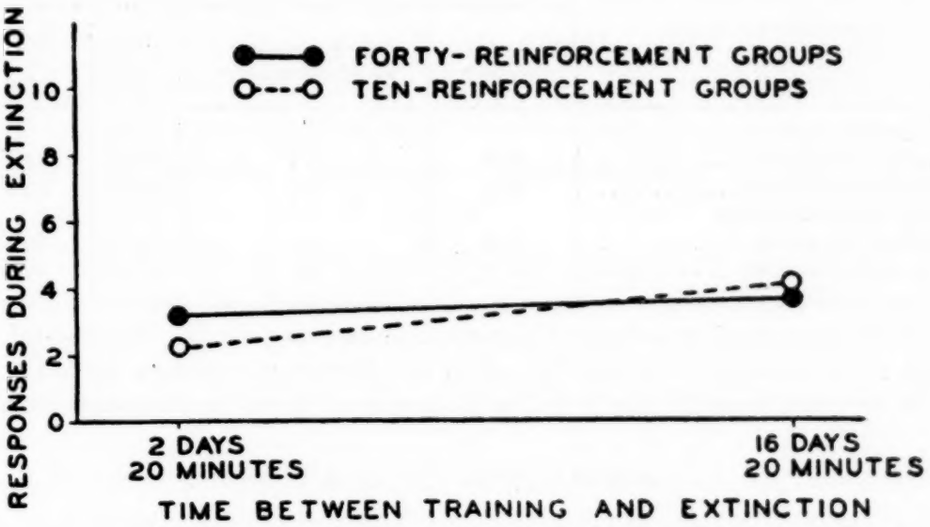

FIG. 4. Spontaneous recovery during a short temporal interval, measured by a third extinction twenty minutes after the second.

The larger resistance to extinction is still found at the fifteen-day retention interval, even after two previous extinctions. Through an oversight, one rat in the ten-reinforcement, one-day retention group was not given this third extinction, so that the value shown above is the mean for nine rats. The forty-reinforcement, one-day retention group also contains nine animals, while the other two groups have ten each.

second extinctions adds further evidence to support the hypothesis presented earlier in the discussion. It should be noted that in Table II the number of responses in the second extinction is a fairly constant per cent of those in the first, except with the forty-reinforcement, 15-day retention group. If it is assumed that the rats again became habituated to the experimental situation during the first extinction, then this disproportionate amount of spontaneous recovery should not occur between the second and third extinctions for any of the groups. In Table III this is found to be the case. The ratio of responses at the third extinction to those at the second is approximately the same for all groups, presumably showing that the loss of habituation, as well as the spontaneous recovery, is now similar in each of the four groups.

TABLE III

COMPARISON OF THE NUMBERS OF RESPONSES AT THE SECOND AND THIRD EXTINCTIONS FOR ALL EXPERIMENTAL GROUPS

Experimental Group	Mean Responses			
	Second Extinction	Third Extinction 20 Minutes Later	2nd Minus 3rd	% 3rd is of 2nd
Ten reinforcements				
1-day retention	12.6	2.1	10.5	17%
15-day retention	17.5	3.9	13.6	22%
Forty reinforcements				
1-day retention	17.8	3.5	14.3	20%
15-day retention	19.7	3.7	16.0	19%

With two exceptions each mean represents the data for ten rats. The 40-reinforcement, 1-day retention group contains only 9, and through an oversight one of the rats in the 10-reinforcement, 1-day retention group was not given the third extinction.

SUMMARY AND CONCLUSIONS

1. Because of an increasing tendency in the literature to indentify the Thorndikian (rewarded) response with the conditioned response, an experiment was performed to determine whether the Thorndikian response shows an increase in strength during retention (as the conditioned response does) or follows the 'law of disuse' and shows a decrement.

2. Thirty-nine male rats were trained to depress a short horizontal bar to obtain a pellet of food. One group of twenty rats received ten reinforcements, while the other nineteen rats were given forty, in daily sessions of ten trials each. Half of each group of rats were extinguished one day after training and the other half fifteen days after training. All responses were stylographically recorded.

3. A plot of the time for ten reinforcements on the successive days of training for the forty-reinforcement group shows a negatively accelerated decrement. This indicates a decrease in latency and an increase in frequency, a change similar to that in the acquisition of conditioned responses.

4. A rho of .69 ± .18 was found between the time necessary for forty reinforcements and number of responses during extinction one day after training. This value contrasts with

the correlation of $-.77 \pm .14$ obtained in an earlier experiment when extinction followed immediately after the last reinforcement.

5. With both the ten- and forty-reinforcement groups, the animals undergoing extinction 15 days after training made a greater number of extinction-responses than those extinguished 1 day after training. Thus, the Thorndikian response shows a rise in the retention curve similar to the one for the conditioned eye-lid response reported by Hilgard and Campbell.

An hypothesis to account for this increased resistance to extinction after the fifteen-day interval is formulated in terms of loss of habituation to the total experimental situation. An experiment is proposed by which the hypothesis may be tested.

6. After the first extinction, which was a test for retention, a second was given twenty-four hours later to all four experimental groups in order to determine the amount of spontaneous recovery. The number of responses made after this spontaneous-recovery period was found to be 42 percent or 43 percent of the responses made at the first extinction for all except the forty-reinforcement, fifteen-day retention group, which gave only 28 percent. A tentative explanation in terms of the habituation-hypothesis was presented for this difference.

7. All rats underwent a third extinction, twenty minutes after the second, in order to test for spontaneous recovery after a short temporal interval. Since all groups had opportunity to become habituated to the complex of stimuli in the experimental boxes during the two preceding extinctions, the ratio of responses during the third extinction to those in the second should, according to the hypothesis mentioned above, be fairly constant for all groups. This was found to be true, the values being 17 percent, 19 percent, 20 percent, and 22 percent.

8. From a comparison of the results of this experiment and analogous data from investigations of conditioning it may be concluded that Thorndikian and conditioned responses are

functionally similar in the direction of change in strength during short retention-intervals.

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THE RELATION OF MUSCLE ACTION POTENTIALS TO DIFFICULTY AND FRUSTRATION

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Results of a recent study by the writer (**2**) were taken to favor an intimate correspondence between muscular activity and amount of psychological labor an individual is performing; a relationship such that an increase in psychological labor is necessarily manifested by an increase in the muscular activity. A suggested implication of such a principle as was observed is that, other things being equal, the performance of more difficult work should show itself in greater muscular activity than produced by the performance of a less difficult task.

The present paper reports an experimental investigation of this latter hypothesis, undertaken to check the principle that peripheral activity is a part of the psychological processes.

In using the concept of difficulty two senses of the term ought to be distinguished. In psychological work, the difficulty of a problem has, of course, almost always been defined in terms of the number of cases in a given population able to solve it, or some function of that number, or by the amount of the problem that can be solved, or some function of that number. Such definitions as these have been the starting point in Woodrow's (**8**) recent analysis and his plan for measurement of difficulty. In this sense difficulty is relative to the abilities of some particular individual or group at a given time. Material which possessed a high grade of difficulty for children six years old might be of very low difficulty for them when they were two years older. Difficulty might be described as the reciprocal or complement of ability, ability, of course, being subject to change. In the experiment previously referred to it was established that with practice (and increased skill) in certain performance, subjects showed a decreasing amount of concomitant muscular activity. In the light of this

first conception of difficulty, it would be merely a restatement of that result to say that a decrease in difficulty of problems is accompanied by decrease in muscular action potentials; that, for the situation concerned there is a positive relation between difficulty of task and muscular activity of subjects engaged therein. To extend this conclusion to another situation, in which degrees of difficulty are supplied by varying tasks instead of changing subjects' abilities, is the chief purpose of the study here reported.

The second rather popular usage of the term difficulty, which may sometimes be confused with the first sense in psychological writing, refers to some permanent characteristic of material, unchanging from individual to individual or group to group, and unaffected by variations in a performer's ability. Experimentally the relative difficulty of two items, according to such a conception, would be determined, possibly, by the ease with which they could be performed by a person or group with equal practice on both. There seems to be no work formally directed at establishing difficulty in this sense as a counterpart of the innate factor in ability, but it would hardly be safe to neglect the possibility that difficulty in the first sense may be conditioned in part upon this factor as well as upon an individual's preceding experience.

It is, of course, difficulty in the first sense with which the present work is directly concerned. In connection with a series of tasks graded with respect to difficulty another concept current in recent psychological writing appears: if difficulty is sufficiently great, frustration may result. Whether this is a different sort of phenomena from mere response to difficulty investigation such as the present should be able to decide. Lewin's (**6**) and Kantor's (**5**) treatment of the situation would perhaps lead one to expect a disorganized response with profound bodily disturbance. On the other hand Clites (**1**) found failure in a prescribed task to evoke less bodily disturbance than a success.

An incidental problem of the present study is the comparison of different muscular regions in their activity during the sitting, since simultaneous records were taken from two parts of the body.

Apparatus

The recording apparatus consisted of two amplifier-oscillograph combinations identical with the one previously described (2). The two 3-inch cathode ray tubes were placed at right angles to each other before the moving film recording camera. A mirror placed at 45 degrees served to make the light from one parallel to that of the other. (The oscillographs can not be placed close enough together to be photographed if they are side by side.) The argon-mercury time flasher previously described was placed so as to record between the two oscillograph lines. Sensitivity of amplifier A was such as to produce a deflection of 2.5 mm. on the oscillograph screen (one direction) per microvolt input; corresponding figure for amplifier B was 3.3 mm. per microvolt input. The same batteries were used for both amplifiers. Therefore careful tests were made to check any possible inter-coupling. With the active lead to one of the amplifiers disconnected a potential impressed on the other amplifier produced no discernible disturbance in the first.

Since the two amplifiers had a common ground connection they had one electrode in common. This was a felt pad 3 inches by 6 inches and ½ inch thick, soaked in saline and placed on the upper arm. Previous analysis (3) indicated that action potentials occuring under this electrode do not affect the amplifiers to any appreciable degree. The active electrodes were screw heads of nickel-plated steel about 5 mm. in diameter. These were slightly moistened with saline at the beginning of a sitting. One, connected to the A amplifier and oscillograph, was placed on the dorsal surface of the right forearm over the extensor digitalis communis. The largest action potentials could be obtained from this region by asking the subject either to contract or extend the fingers vigorously, though any movement of the hand or arm produced considerable activity here. The second active electrode was placed, for the largest group of subjects, on the side of the neck over the right lobe of the thyroid gland. It was therefore over the sterno-cleido-mastoid, and, in fact, picked up the greatest disturbance when this muscle was voluntarily contracted. Tests showed, however, rather large deflections here whenever the subject moved his head in any direction or engaged in phonation. This latter effect probably arises from involvement of the sterno-cleido-mastoid, rather than directly from the internal muscles of the larynx which are rather small and distant from the electrode. (It is doubtful whether the action of these could be recorded by means of an external electrode.) On a small group of subjects, separate treatment of which will be described, the neck electrode was placed somewhat higher for purposes of comparison. In these cases it was located on the side of the neck tangent to the upper right boundary of the larynx.

Methods

In view of the above considerations it seemed desirable to conduct a systematic study of the effects of difficulty in an experiment in which (1) degrees of difficulty, in some sense, could be quantatively determined, and (2) the degree of difficulty could be increased to a point at which the subjects would be unable to perform the assigned work.

A group of 44 subjects, adult men and women in about equal proportions, was used. The work material submitted to them consisted of five groups of number series problems, ranging from very simple to fairly complex, and including one which had no solution whatever. Because it was desirable to have subjects working at least a minute consecutively in order to obtain sufficient record, the problems were used in groups rather than singly, five simple problems constituting one group, the one insoluble

problem a group by itself, and the intermediate groups consisting of two, three and four problems. The same order of presentation was used for all subjects, an order intended to intersperse easy and difficult work.

Subjects were put into the shielded booth with electrodes attached. They were told that the work would be explained later and instructed to sit quietly and relax thoroughly, as though they intended to go to sleep. Arm and neck action potentials were observed on the oscillograph while the subjects were doing this, and the degree of relaxation estimated on the basis of previous experience with other subjects. (An action potential level of less than 10 microvolts, approximate, was regarded as a condition of relaxation.) If the action potentials tended to remain high the attention of the subject was called to tensions in the arm or neck, and he was asked to 'loosen up.' A noteworthy incidental observation was that after such instruction the first reaction of the subject was almost invariably to become more tense, then in thirty seconds or a minute relaxation usually did appear. This process of relaxation usually took about five minutes. Thereupon the door of the booth was opened and instructions were given the subject to begin work on the number series problems (which were then placed before him) when he was signalled to do so. The nature of the problems was explained and illustrations given until the subject thought he understood what he was to do. The subject was told there was no time limit, but that he was to work as rapidly as possible; he was also informed that he could give up the assigned task at any time he thought he was unable to proceed. It was especially emphasized that the subject should report immediately when he stopped work, whether giving up or completing the task. No writing was required during the work period, and the subject was therefore told not to shift position. He was informed that opportunity would be given as soon as each group was finished for him to write in the answers he had obtained.

Records on the oscillograph were taken fifteen seconds after the beginning of the work period and every thirty seconds thereafter until the subject ceased work. The duration of each record was approximately five seconds, this constituting a sample of the subjects' muscular tension during that part of the work period.

As soon as the subject had ceased work on a group of problems and written the answers (no records being taken during the writing) another group of problems was placed before him, and he was instructed to relax before the next signal to begin work. The signal was not given until the original level of relaxation had been reached. In this way any build-up of tension from problem to problem was avoided. A final rest period was given at the end of the sitting. The subjects were not told the answers to the problems until they had been brought out of the experimental booth.

This procedure with the forty-four subjects yielded in excess of a thousand photographic samples of action potentials, each, except in a few cases, giving parallel records from arm and neck, each record being one to three feet long, depending on the speed of the camera motor and the length of exposure. In order to make possible any treatment of the large quantity of data a simplified technique of measurement was clearly necessary. That finally used was to select for measurement the three largest deflections in each sample. These were measured to the nearest hundredth of an inch. The average of the three was taken as a rather arbitrary indication of the level of action potentials represented by any one sample. Inasmuch as there were two parallel records the total number of measurements made was greater than 6000.

For almost all comparisons of this study a conversion of these data to percentages was used. It was felt that individual differences in the amount of tissue overlying active muscle fibers might be one factor influencing the apparent size of the action

potentials. (This is a purely logical consideration, for the writer knows of no comparison of action potentials in fat and thin people.) If however the action potentials of one period are expressed as a ratio of some standard action potential level in the same person, such individual differences are cancelled in their effects. Hence a percentage was computed by dividing each average as described above by the level of action potentials found in the same individual during the final rest period. (On occasion this ratio was replaced by another, as will be explained later.)

Results

1. *Comparison of action potentials in the arm with those in the neck.*—A comparison of the level of 'rest' action potentials in the parts of the body measured requires, of course, the use of the absolute magnitudes rather than any percentage value. In Table I are shown the average values of the action poten-

TABLE I

Absolute Activity Levels for Arm and Neck During Rest Periods
(In Microvolts of Peak Potentials)

	N	First	Last	Both
Average-Neck (Lower position)	24	9.3	10.2	9.8
S.D.				2.2
$\sigma_{av.}$				.69
Average-Neck (Upper position)	5	9.1	12.8	10.8
Average-Arm	24	5.9	5.7	5.8
S.D.				1.9
$\sigma_{av.}$				.39
Average-Neck (Lower)—Average-Arm				3.9
ρ				.15
$\sigma_{diff.}$				.74
$\frac{\text{Diff.}}{\sigma_{diff.}}$				5.3

tials for both rest periods combined for a group of subjects, with reliability of the difference. These figures are given in microvolts, and refer, of course, to the average of the three highest peak potentials during a rest period for any one subject. It is apparent that there is a reliably greater output of action potentials from the neck muscles than from the arm muscles. The difference may be due to difference in depth of the muscles under the skin surface though it more probably represents the fact that the neck muscles were continuously active in supporting the head. In six cases, it will be recalled the neck electrode was placed higher, above the larynx. The

rest period level here, also shown in the table, is again not significantly different from the others.

In comparing activity during the work period in the three regions the percentage figures can be used most conveniently. Table II shows the average work period readings in these

TABLE II

ACTION POTENTIALS FROM ARM AND NECK DURING WORK

(Expressed as Percent of Action Potentials During Rest)

	Neck (Lower and Upper Position)	Arm	Neck (Upper Position)
N	44	41	6
Av.	132.5	190.8	124.2
S.D.	35.2	106.8	
Arm-Neck	58.3		
ρ	.14		
$\sigma_{diff.}$	16.8		
$\frac{Diff.}{\sigma_{diff.}}$	3.45		

terms, with reliability of the difference for the two major electrode locations. Evidently a pronounced difference exists here, the arm being far more subject to increased activity during mental work than is the neck. This obtains in the figures displayed in spite of the fact that the arm recording unit ran off the scale far more frequently than did the neck recording unit. Approximately 240 readings on the arm (out of some 3000) were greater than full scale deflections, and were scored simply as full scale readings, whereas but 40 of the readings from the neck were off scale. (This was partly because of slightly greater sensitivity of the arm instrument.) The few readings taken from the upper neck position are not significantly different in magnitude from those at the lower position.

The significant trend of these figures is made comprehensible, perhaps, by recalling that the arm electrode was placed over the extensor muscle of the fingers, members which are more mobile in gesture than the head and jaws, and the fact that the rest level was greater for the neck.

The question of co-variance of activity in the two regions remains to be investigated. Obviously there is a relationship present, since both show an increase during the work periods, as will be discussed more fully later. However, to discover the closeness of this relation a correlation coefficient was computed for readings during the work period. The unit used in this correlation was the single run of the camera. The value of this coefficient is $.352 \pm .050$. This would probably be raised substantially if corrected for attenuation (although no satisfactory means of deriving reliability coefficients is at hand) yet it is certain that we are dealing with a coefficient which is significantly less than unity, and yet represents an actual positive correlation. The implication is that the muscular tensions are a diffuse bodily activity differing not only in intensity in various regions, but in the occurrence of different patterns of activity at different times, patterns which have certain elements, rather small perhaps, in common.

2. *Comparison of action potentials during work and rest.*—Excess of action potentials in the work periods over those in the rest periods is represented by any value greater than 100 (when computed according to the ratio technique). Reference to Table II shows such an excess in the case of both arm and neck measurements, the excess being very large in relation to the standard error of the average. The upper position of the neck electrode gives figures substantially the same as the lower. (In the remaining computations the two will be taken together.) In 76 percent of the cases the reading from the neck was greater during work than during rest; in 86 percent of the cases the reading or the arm was greater for work than for rest. These figures are of the same magnitude as those reported earlier by the writer (**2**) for other tasks, and follow the general expectation from Freeman's results (**4**). They are considerably more positive than those of Max (**7**) on a small group of hearing subjects, but resemble rather closely his results with the deaf.

3. *Comparison of action potentials during successful solution with those during failure.*—The categories of success and failure are suggested by the question whether frustration provokes a

large amount of muscular activity, and by the results of Clites (1) dealing with such a classification. The primary criterion of success or failure used was the report of the subject, since this appeared likely to represent frustration or non-frustration better than actual correctness of solution. The first comparison was made by combining into an average the figures representing the level of action potential during each 'successful' solution, and obtaining a similar figure for all 'failure' solutions. The averages of all first readings and all last readings were also computed. These figures appear in Table III with the reliabilities of the differences of the aver-

TABLE III

ACTION POTENTIALS DURING 'SUCCESSFUL' AND 'UNSUCCESSFUL' SOLUTION OF PROBLEMS

	Neck		Arm	
	Success	Failure	Success	Failure
Number of Problems	124.	60.	136.	63.
First Reading	123.5	133.0	177.2	170.1
Last Reading	134.7	140.7	204.5	183.9
Average	128.5	138.0	194.8	181.4
S.D.	67.	49.	129.	99.
Difference (Success − Failure)	−9.5		13.4	
$\sigma_{diff.}$	7.4		13.3	
$\frac{\text{Difference}}{\sigma_{diff.}}$	−1.28		1.01	

ages. Since the differences are in opposite directions for arm and neck measurements and have insignificant critical ratios it must be concluded that this method of comparing success and failure shows no difference in action potential between the two.

Further treatment of the data, however, is indicated. In Table IV the unit of computation was the problem. Hence certain subjects were given heavy weighting in one average, and others in the other according to the number of success reported. To obviate the possible influences of individual differences in level of activity during problem solving averages were computed with the subject as a unit. Two measures

were computed for each subject, the action potential level during all reported successes, and the level during all reported failures. General averages of these two figures for arm and

TABLE IV

ACTION POTENTIALS DURING 'SUCCESS' AND 'FAILURE' WITH EQUAL WEIGHTS FOR EACH SUBJECT

	Neck		Arm	
	Success	Failure	Success	Failure
Number of Subjects	34	34	31	31
Average	128.4	136.3	178.7	195.3
S.D.	36.3	32.7	62.8	98.6
Difference (Success − Failure)	−7.9		−16.6	
ρ	.59		.95	
$\sigma_{diff.}$	5.4		8.0	
$\frac{\text{Difference}}{\sigma_{diff.}}$	−1.5		− 2.1	

neck were then obtained. Those are shown with the reliabilities of the differences in Table IV. It is to be noted that in this comparison there is a correlation between 'success' and 'failure' action potentials which needs to be taken into account in making the comparison. In view of the very small critical ratios there is evidently no difference between successful and unsuccessful work here either. The correlation between action potential level during 'success' and that during 'failure' is significant. There is evidently a great deal of individual consistency about a subject's muscular activity level during work.

Yet another method of calculation was employed: making a comparison similar to the preceding, with actual correctness of solution as the criterion of success. The number of available cases in this treatment is reduced, since a certain percentage of the subjects made some error in each problem group. Data are summarized in Table V. Again no difference between the two categories appears.

From the three methods of approach it appears that Clites' finding of greater activity during successful solution cannot be

generalized in simple fashion to cover the results of the present experiment. Neither is there evidence of a muscular disturbance produced by frustration. As far as these data go it is possible, of course, that both tendencies were operative, and mutally cancelled one another.

TABLE V

ACTION POTENTIALS ACCOMPANYING CORRECT AND INCORRECT SOLUTIONS, WITH EQUAL WEIGHT FOR EACH SUBJECT

	Neck		Arm	
	Correct	Incorrect	Correct	Incorrect
Number of Subjects	33	31	31	29
Average	124.3	121.7	174.3	193.6
S.D.	34.4	65.2	143.0	101.0
Difference (Correct − Incorrect)	2.6		−19.3	
ρ	.92		.68	
$\sigma_{Diff.}$	6.1		19.0	
$\frac{\text{Difference}}{\sigma_{Diff.}}$	.4		− 1.0	

4. *The relation between the activity level of an individual and the number of problems 'solved.'*—In two comparisons of the preceding section the effect of individual differences in muscular tension during work was eliminated. It is also of interest to investigate them. Possibly the individual who characteristically becomes tense while working reports or achieves more successes in the solution of problems. To study such a possibility the average action potential level during the work

TABLE VI

AVERAGE ACTION POTENTIALS IN RELATION TO NUMBER OF PROBLEMS REPORTED SOLVED

% 'Solved'	*N*	Action Potentials	
		Neck	Arm
0–20	2	110.3	106.3
20–40	4	157.7	163.8
40–60	6	132.1	190.7
60–80	14	134.2	167.0
80–100	10	116.3	199.3
100	9	129.4	219.1

TABLE VII

RELATION BETWEEN NUMBER OF PROBLEM GROUPS CORRECTLY SOLVED AND LEVEL OF ACTION POTENTIAL

% 'Solved'	*N*	Neck	Arm
0–20	12	138.3	196.1
20–40	6	135.1	141.3
40–60	15	123.5	188.7
60–80	6	115.5	170.5

period was computed for each subject. Tables VI and VII show these averages in relation to the number of problems reported solved, and to the number actually solved. There is but a slight relation, if any, observable in the case of the reported successes. At the extremes there is a suggestion that those who claimed little success were but slightly aroused above the resting condition, that those who optimistically reported many successes were considerably tensed during the work period.

It would be desirable to investigate the relation between successes, real and reported, and customary 'rest' level. Present data, however, would be unrelevant because of the experimenter's insistence upon a certain degree of relaxation before work.

5. *The relation between level of action potentials and the difficulty of the task.*—In order to approach the fundamental question of this experiment it has been necessary to explore a number of possible conditioning factors. With information on these it is possible to proceed to the difficulty relation. The ratio for action potentials in the work period to action potentials in the rest period, as previously described, was used where the whole group was concerned. Individual differences in work and rest levels do not affect the averages here since each individual worked each problem. The average activity ratio for the whole group of subjects for each problem group was therefore computed, and appears with standard deviation in Table VIII. Several measures of 'difficulty' are possible: time, number of correct solutions, and number of reported successes. Time, as will be seen in Table VIII, does not show

a high degree of relation to the other two. Reported successes appear to be a more intimate measure than actual success for the purpose, inasmuch as difficulty as the subjects saw it would influence them more directly than difficulty as inferred

TABLE VIII

RELATION BETWEEN DIFFICULTY OF PROBLEMS AND ACTION POTENTIAL LEVEL

Problem Group	% Reported Failure	% Actual Failure	Av. Time (Seconds)	Av. Action Potential		S.D.	
				Neck	Arm	Neck	Arm
I	29	66	138	128.1	177.5	53	110
II	44	96	176	130.7	198.7	33	142
III	7	66	93	120.9	174.5	34	140
IV	70	100	170	142.7	207.5	36	117
V	5	32	44	118.7	184.0	66	179

from their work. Both latter methods of measuring difficulty yield the same relationship, which is shown graphically in Fig. 1. With increased difficulty there is a regular increase in muscular activity as indicated by action potentials. The increases in arm and neck muscle activity are parallel, with the arm muscles, as previously shown, displaying a greater percentage of increase over rest level.

It is further desirable to study the results of success and failures separately. For this purpose the percentage of increase over rest level is not a satisfactory measure of muscular activity during the working of particular problem groups, since the 'success' group of subjects and the 'failure' group of subjects for any one problem would necessarily consist of different individuals who might have a personal tendency to greater or less muscular activity during any sort of work. These individuals would shift from the success or failure group to the other from problem to problem and the final results would be distorted by whatever individual differences exist in the respect mentioned.

Therefore a new measure of an individual's muscular activity during the working of a problem group was developed. For the purpose the average action potential level during any particular work period was expressed as a percentage of the

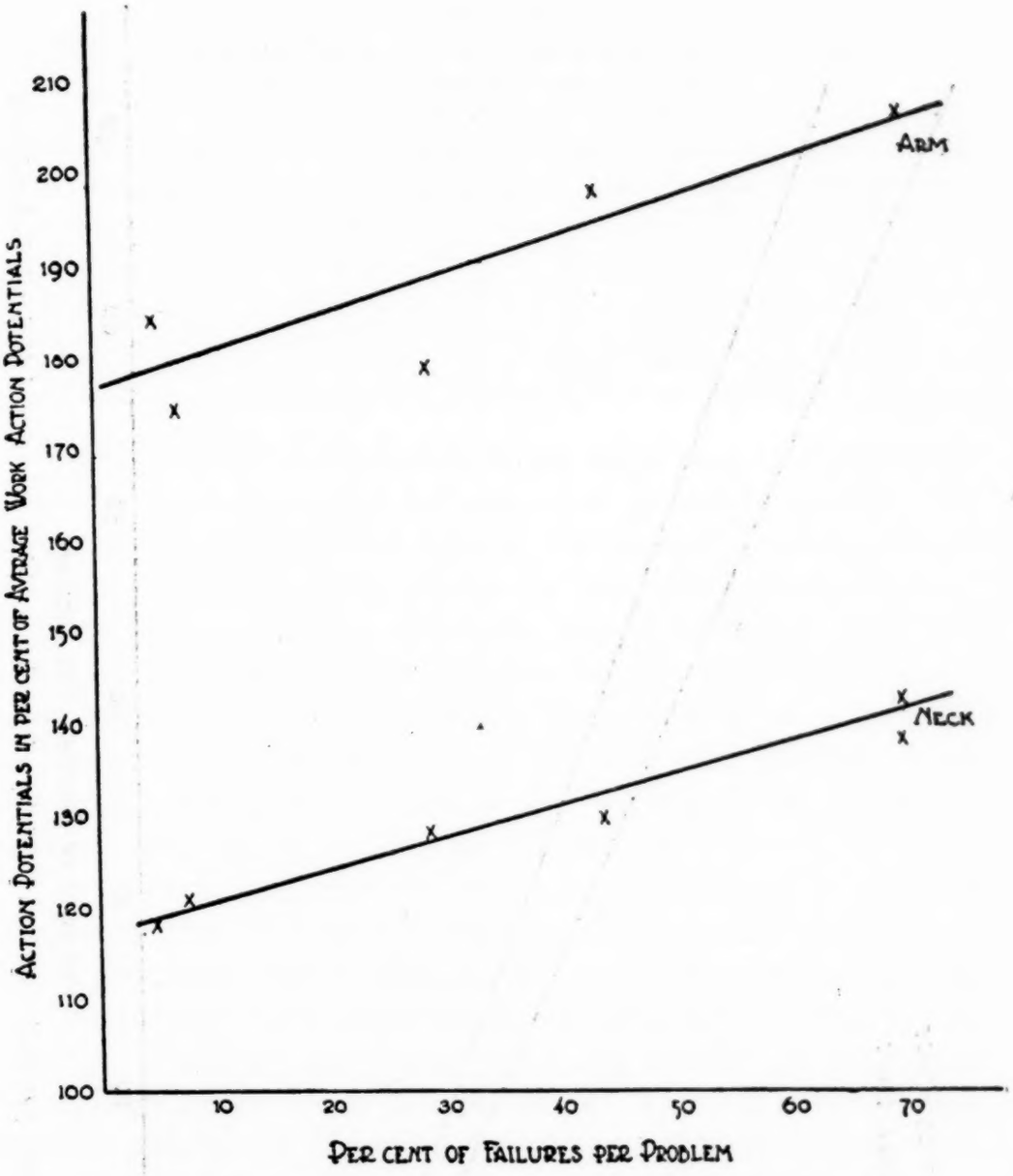

FIG. 1. Relation between action potential level and difficulty of problems.

average action potential level during all work periods. Figures for arm and neck activity were grouped together for this purpose by averaging the two after they had been computed separately. Computations were made on the basis of subject's reports regarding success and failure rather than on the basis of correctness of answer for the aforementioned theoretical reason, and because a better distribution existed when computed on this basis. The results are shown in Table IX and the trends are graphically represented in Fig. 2.

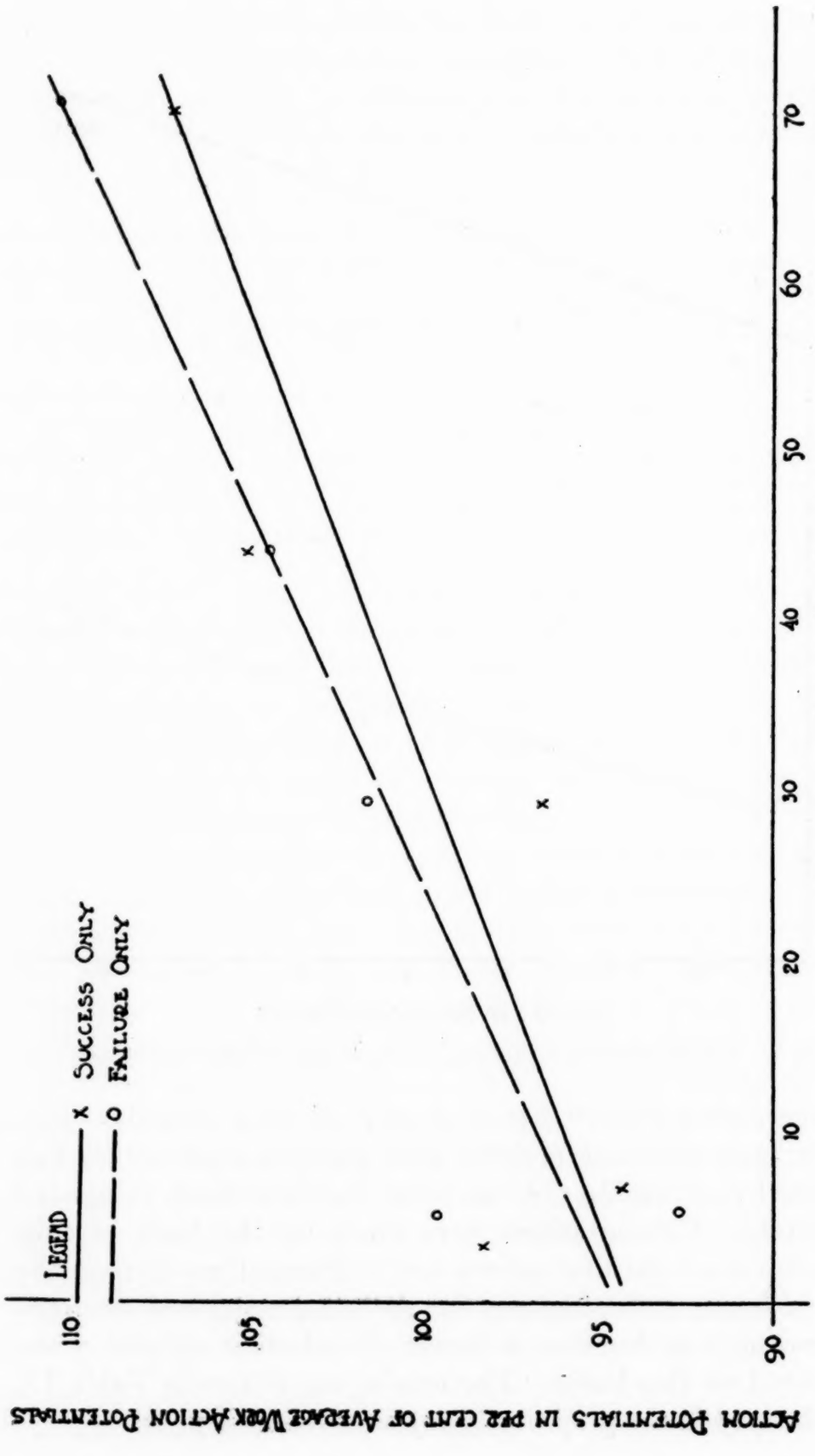

Fig. 2. Relation between action potential level and difficulty of problems, with 'success' and 'failure' distinguished.

TABLE IX

RELATION BETWEEN DIFFICULTY OF PROBLEMS AND ACTION POTENTIAL LEVEL DURING 'SUCCESS' AND 'FAILURE'
(For Explanation of Values see Text)

Problem Group	% 'Failure'	Action Potential Level 'Success'	Action Potential Level 'Failure'
I	29	96.7	101.8
II	44	105.1	104.7
III	7	94.5	99.2
IV	70	107.6	110.9
V	5	98.5	92.0

The tendency of the results is the same as in the preceding case where successes and failures were grouped together. It is not so surprising in the light of the preceding computation that the 'success' group shows an increasing percentage of activity with increasing difficulty, but it is strange that the group of 'failures' shows the same trend. Apparently more muscular activity is involved in the solution of a difficult problem than in the solution of an easy one, likewise more muscular activity is involved in the 'giving up' of a difficult problem than in the 'giving up' of an easy one.

To explain this curious result among failures it may be suggested that individuals who had succeeded in 'solving' easier problems were stimulated to greater effort before giving up when they were confronted by difficulty. (The group marked 'Failures' does not of course consist of the same individuals at all levels of difficulty.) This type of reaction would produce the observed trend even after individual differences in work period muscular activity have been balanced out by the method indicated.

DISCUSSION

The major question stated at the beginning of this report is given an affirmative answer: There is an increase in muscular activity during solution of a problem corresponding in amount to the difficulty of the problem when difficulty is measured in terms of the proportion of subjects failing the problem. Naturally it is not to be concluded that difficulty in this sense is the only influential factor. Certain others have been pre-

viously established, as already mentioned. Of these it is possible that practice is simply a reciprocal of difficulty, although in elaborating an algebraic statement of the relationships it would be safer at present to allow place for both terms. Adding the difficulty term, therefore, to the functional equation suggested previously (2) gives $\Delta AP = f$ (Work, Distraction, $\frac{1}{\text{Practice}}$, Difficulty) $- f$ (Rest Period 'Work') where ΔAP refers to an increase in action potentials. The first term in the right hand member of this equation is the determiner of what the writer has referred to as 'psychological labor.'

For a peripheral theory of psychological processes a question is always raised whether such a relationship as stated by the equation is a necessary one, or whether special cases might arise in which psychological processes as indicated in the right hand member might result in no increase in action potentials, thus making $\Delta AP = 0$ and the equation invalid. It is very difficult to arrive at a definite answer to such a question, since it is practically necessary to work with averages of a number of readings for an individual or for a group in this type of investigation. A stumbling block is also introduced by the necessity that there be actually less psychological labor in the rest period than in the work period. Attention may be called, however, to the very large proportion of cases in the present investigation showing some degree of increase. Conservatively, one may answer the question by saying that ordinarily the equation holds, that any psychological process, if such there be, which stands outside it is of a different nature from those ordinarily encountered.

The results of this investigation agree well with the hypothesis that muscular tensions form a part of the ordinary psychological process. In this study it is further indicated that muscular tensions are not evenly distributed over the organisms during a period of labor, being more pronounced in the arm than in the neck. Further investigations of the patterns of their distribution are of course suggested.

It has not appeared necessary to add frustration as a factor

influencing the appearance of an increase in muscle action potentials. So far as the present results are concerned there is a continuous relation between muscular activity and difficulty of task, with no sharp break which might be taken as indicative of the occurrence of frustration. The level of muscular activity for failures on a given problem was not significantly higher than that for successes. Of course it is immaterial whether the graded problem series in this investigation is spoken of as a series of increasing difficulty or a series of increasing frustration, but whichever is chosen a second term appears to be superfluous.

Likewise it may be noticed that the present study contributes no supporting data to the positive relation shown in the equation between 'Work' and increase of action potential. There is no significant excess of muscular activity in cases of success over that in cases of failure. Nevertheless this discussion has assumed the validity of such a relationship on the basis of the studies previously discussed. In the present experiments its operation is taken to be obscured by other factors, particularly by that of difficulty, which the experiment was set up to emphasize.

Summary

1. Muscular activity was studied by the action potential method in a group of 44 subjects working on number series problems whose difficulty was specified in terms of number succeeding on each group.

2. Muscle action potentials from the arm showed lower level of rest action potentials but a much greater percentage of increase during the work periods.

3. Muscle action potentials accompanying successes and failures reported and actual were not significantly different.

4. Individual consistencies in muscular activity are pronounced.

5. With increasing difficulty of task there was a corresponding increase in accompanying action potentials in both arm and in neck, and accompanying both reported success and reported failure.

6. It was concluded that the factor of difficulty should be added to an equation describing the relation between psychological process and muscle action potentials.

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FOCI OF ACTIVITY OF THE ALPHA RHYTHM IN THE HUMAN ELECTRO-ENCEPHALOGRAM

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The alpha rhythm, a prominent feature of the human electro-encephalogram, has been reported by Adrian and Matthews (1) to originate chiefly in the occipital region of the brain. Berger (3), on the contrary, holds that it arises from all regions of the cerebral cortex. Adrian and Matthews base their view upon the following observations made by them, namely, that alpha waves are of greater magnitude over the occipital region than elsewhere, that they are more effectively suppressed by visual than by other forms of sensory stimulation, and finally that the frequency of the alpha waves in all regions may be made to follow, within limits, the frequency of a flickering visual stimulus.

More recently, Adrian and Yamagiwa (2), in mapping the distribution of alpha potentials over the surface of the head by recording simultaneously from as many as four adjacent areas, found a small area in the occipital region of each cerebral hemisphere which they considered the focus of activity, or the origin of the alpha rhythm. Alpha waves simultaneously recorded from opposite sides of this area were reversed in phase, whereas those from the same side were in phase or synchronized. Several subjects were studied by them and it was found that the position of the focus ranged from about 10½ to 13 inches from the nasion and from 1 to 2½ inches from the mid-line.

In the course of a number of explorations of the surface of the head for other purposes during the last two years, reversals of phase were frequently observed in regions other than those described as focal areas by Adrian and Yamagiwa. In addition, it was also noticed that alpha waves simultaneously recorded from occipital and parietal, or occipital and temporal

regions showed independent variations in pattern and rhythm and were often affected differently by sensory stimulation. These observations pointed to separate sources of the alpha waves recorded from different areas. The present study was undertaken, therefore, to investigate this possibility more thoroughly by systematic exploration of the surface of the head in a number of subjects.

Apparatus and Procedure

The amplifying and recording system has been described elsewhere (10). Briefly, it consisted of two matched amplifiers of the resistance-capacity coupled type with provisions for varying the time-constant, pre-amplifiers with balanced input circuits, and a Westinghouse type PA oscillograph with matched recording units. This equipment permitted simultaneous, but independent recording from any two areas. The electrodes consisted of gold discs, 8 mm. in diameter, which were sunk in small bakelite blocks and attached to the surface of the head by means of bandages. The cup of the electrode block was filled with an electrode jelly.

The subjects sat comfortably with eyes closed in a dark and relatively sound-proof, electrically shielded room. Explorations of the surface of the head were made chiefly in longitudinal and horizontal planes. That is, starting from a point slightly below the inion, or the external occipital protuberance electrodes were spaced from 1 to 1½ inches apart along a line extending from back to front, parallel with the mid-line but from 1½ to 2 inches lateralward. Electrodes were also spaced along a horizontal plane, starting from the occipital mid-line about 1 to 2 inches above the inion, and passing around the side of the head to the frontal region. Since only two matched amplifying and recording channels were available records could be obtained from only two pairs of electrodes at a time. However, by shifting the electrodes a series of records was obtained in which the activity of various areas could be compared.

Two methods of recording were used, namely, that of Adrian and Yamagiwa (2) in which the middle member of three electrodes in line served as a common lead to both amplifiers, and that employing two separate pairs of electrodes. The first method is less useful in locating foci of activity since it seems to require almost an exact placement of the middle electrode over a focal point in order to reveal a complete reversal of phase of the alpha waves, whereas the latter method reveals reversals if the focal point lies between the two pairs of electrodes. The polarity of the recording system was so arranged that when the inner members of the two pairs of electrodes in line simultaneously became negative (or positive) with respect to the outer two, the deflections on the record were in opposite directions or out of phase. Hence, when the waves in the two tracings on a record are reversed in phase it presumably means that a center of activity, or a focus, lies between the two pairs of electrodes.

X-ray photographs of the head were sometimes taken with the electrodes in place when a focus of activity was found in order to more accurately localize the position with respect to the underlying brain tissue.

Results

Series of systematic recordings of brain potentials have been made along longitudinal and horizontal planes of the

head in 16 subjects (7 adults and 9 adolescents ranging from 12 to 14 years of age), some of whom have been studied several times. Contrary to the report by Adrian and Yamagiwa (2) of but a single focus in each cerebral hemisphere, in the occipital region, the results indicate that there are at least four distinct foci in each hemisphere. Two of the foci are located over the occipital area, a third over the anterior part of the parietal area, and a fourth over the temporal region.

It is difficult to sharply delimit the foci by the reversal of phase method. However, it appears from the phase relationships of the alpha waves simultaneously recorded from two pairs of electrodes placed in various positions about a focus and connected in different combinations that the occipital foci represent relatively small areas of activity, probably less than one inch in diameter. The activity originating at the center seemingly spreads more or less equally in all directions, but apparently for only a very short distance. The parietal and temporal foci are less sharply defined and seem to represent a more diffuse activity. Further observations have revealed that although a focus may shift suddenly, gradual shifting is more usual and may require from one half to one second to shift sufficiently (perhaps one inch) to alter the phase relationship of the alpha waves from two adjacent pairs of electrodes by 180 degrees. The shifting of a focus is mainly confined to a distance of less than one inch, and much of the time the foci remain quite stationary, even following stimulation which temporarily abolishes the alpha waves.

Figure 1 shows part of a typical series of records from one of the subjects. The first six records were obtained with electrodes in different positions along a longitudinal plane of the head, parallel with, but $1\frac{1}{2}$ inches off the mid-line. The distance of the electrodes from the nasion, measured along the mid-line, is indicated in inches at the left of each record. Reversal of phase of the alpha waves will be noted in records 1, 2, and 5. This indicates that foci of activity lie between $12\frac{3}{4}$ and $14\frac{1}{4}$, $11\frac{1}{2}$ and $12\frac{3}{4}$, and $7\frac{1}{4}$ and $8\frac{3}{4}$ inches, respectively, from the nasion. Reference to Fig. 4 shows that the first two of these positions lie over the occipital area and the third lies

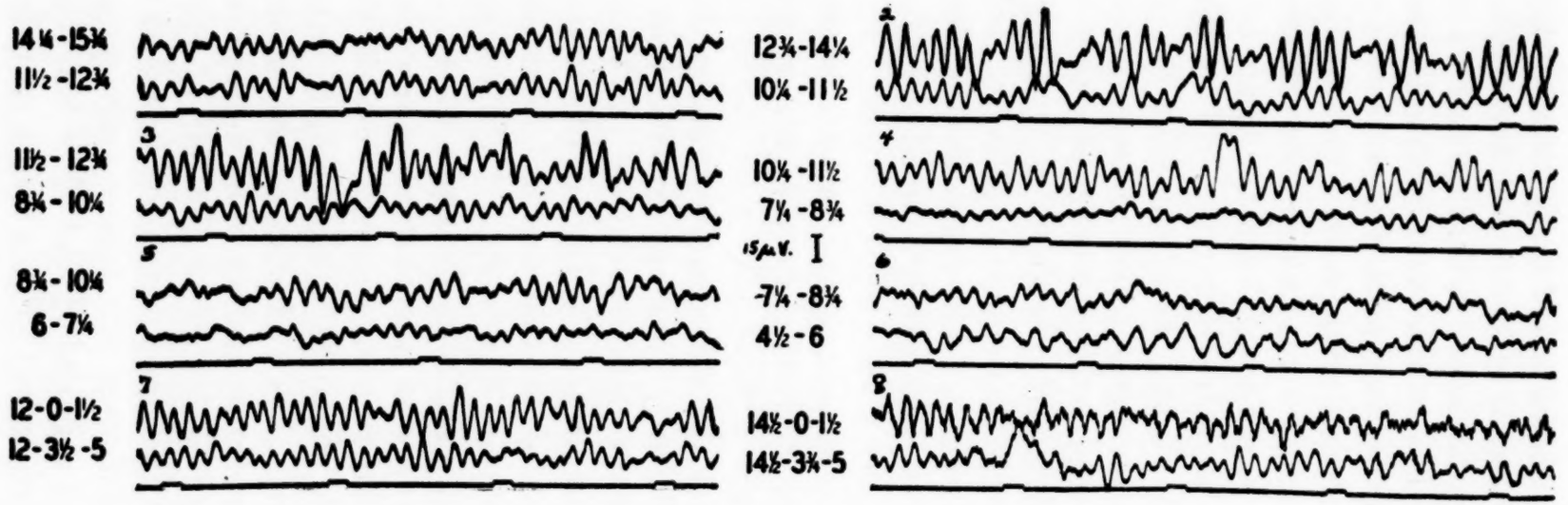

FIG. 1. Brain potentials simultaneously recorded from adjacent areas in longitudinal (records 1 to 6) and horizontal (records 7 to 8) planes of the head, showing reversals of phase of alpha waves in records 1, 2, 5, 7, and 8. The position of the electrodes is indicated at the left of each record. One second intervals are indicated by deviations in the time line at the bottom of all records in this and subsequent figures.

over the anterior part of the parietal area. Records 7 and 8 were obtained with the electrodes in line in horizontal planes of the head. These planes cut the occipital mid-line at 12 and 14½ inches, respectively, from the nasion. The distance of the electrodes from the mid-line is also indicated at the left of each record. In both of the records the alpha waves are completely reversed in phase, indicating that the occipital foci just located in a longitudinal plane lie between 1½ and 3½ inches from the mid-line.

Although alpha-like waves of low amplitude are sometimes observed over the anterior part of the premotor area (area 6aβ) and over the frontal association areas, other types of waves of entirely different frequency and pattern are more prominent there and preclude comparison of phase relationships with alpha waves of the usual frequency in other regions immediately posterior. For example, in record 6 of Fig. 1 the lower tracing from a region over the anterior part of the premotor area shows rhythmic waves at 6 to 7 per second, whereas those in the upper tracing are typical alpha waves of a frequency of about 10 per second. Slow waves ranging in frequency from 3 to 7 per second have frequently been observed over the anterior part of the premotor area and occasionally over the frontal association areas.

Figure 2 shows part of a series of records from another subject. All of the records are from a longitudinal plane 2 inches off the mid-line. The reversal of phase of alpha waves in record 1 indicates that there is a focus of activity between 13 and 14½ inches from the nasion. There is a shifting phase relationship in records 2 and 3, although there is a greater tendency to reversal of phase in record 3. This suggests that the focus is in the neighborhood of 11¾ inches from the nasion and tends to shift anteriorly, although it may occasionally shift posteriorly. This is the only subject of the group in which it was impossible to demonstrate a reversal of phase over the anterior part of the parietal area, the waves from adjacent pairs of electrodes in that region being perfectly synchronized. It is possible that the focus of activity was too diffuse to be revealed by closely spaced electrodes. Other

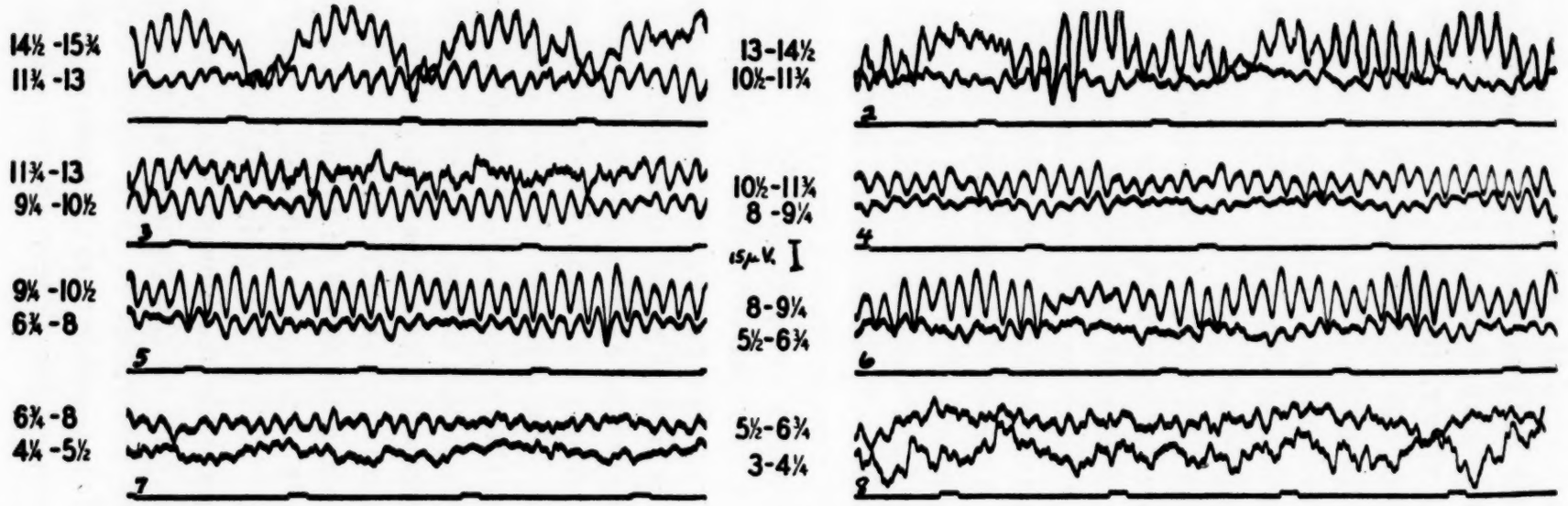

FIG. 2. Records from a longitudinal plane of the head. Foci of activity are indicated by reversals of phase in records 1 and 3. The magnitude of potentials in the upper lines of records 5 and 6 equals that in records 1 and 2 from over the occipital region.

aspects of the records suggest that there is a focus in the anterior part of the parietal area, for the magnitude of the waves in the upper tracings of records 5 and 6 are as large as those from over the occipital region and show even greater regularity. It will also be noted that the waves from the region between the occipital area and the anterior part of the parietal area are smaller than at either of these two points.

Records 1 to 10 of Fig. 3 are part of a series from a third subject. The first seven records were made with the electrodes oriented in a longitudinal plane. Reversals of phase are found only in records 1, 2 and 5 which indicates that foci of activity lie between $12\frac{1}{2}$ and $13\frac{3}{4}$, $11\frac{1}{2}$ and $12\frac{1}{2}$, and $8\frac{1}{4}$ and $9\frac{1}{2}$ inches, respectively, from the nasion. The first two of these foci are over the occipital area and the third is over the anterior part of the parietal area. The occipital foci have been localized between $1\frac{1}{2}$ and $3\frac{1}{2}$ inches from the mid-line. Records 8, 9, and 10 of Fig. 3 are from a horizontal plane which cuts the occipital mid-line $1\frac{1}{2}$ inches above the inion. The figures in parentheses at the left of each record indicate the distance of the electrodes from the occipital mid-line. The reversal of phase of the waves in record 9 indicates that the temporal focus in this case lies between 6 and $7\frac{1}{2}$ inches from the occipital mid-line. Records 11 and 12 of Fig. 3 are from another subject and were also made with the electrodes oriented in a horizontal plane. A fairly consistent reversal of phase may be seen in record 11, thus locating the temporal focus in this subject between 6 and $7\frac{1}{2}$ inches from the occipital mid-line.

In order to indicate the relative positions of the four foci with respect to the underlying brain surface, Fig. 4 is presented. It is a tracing of an X-ray photograph of the head of one of the subjects. A diagrammatic map of the brain surface adapted from that of Foerster and Penfield (**6**) has been fitted to the skull. The positions of the central and parieto-occipital sulci were determined by Chiene's method (**5**) for plotting the relationship of the cranial contents to the surface of the head. The distance from the nasion to the inion, along the mid-line contour of the scalp, has been marked off in inches.

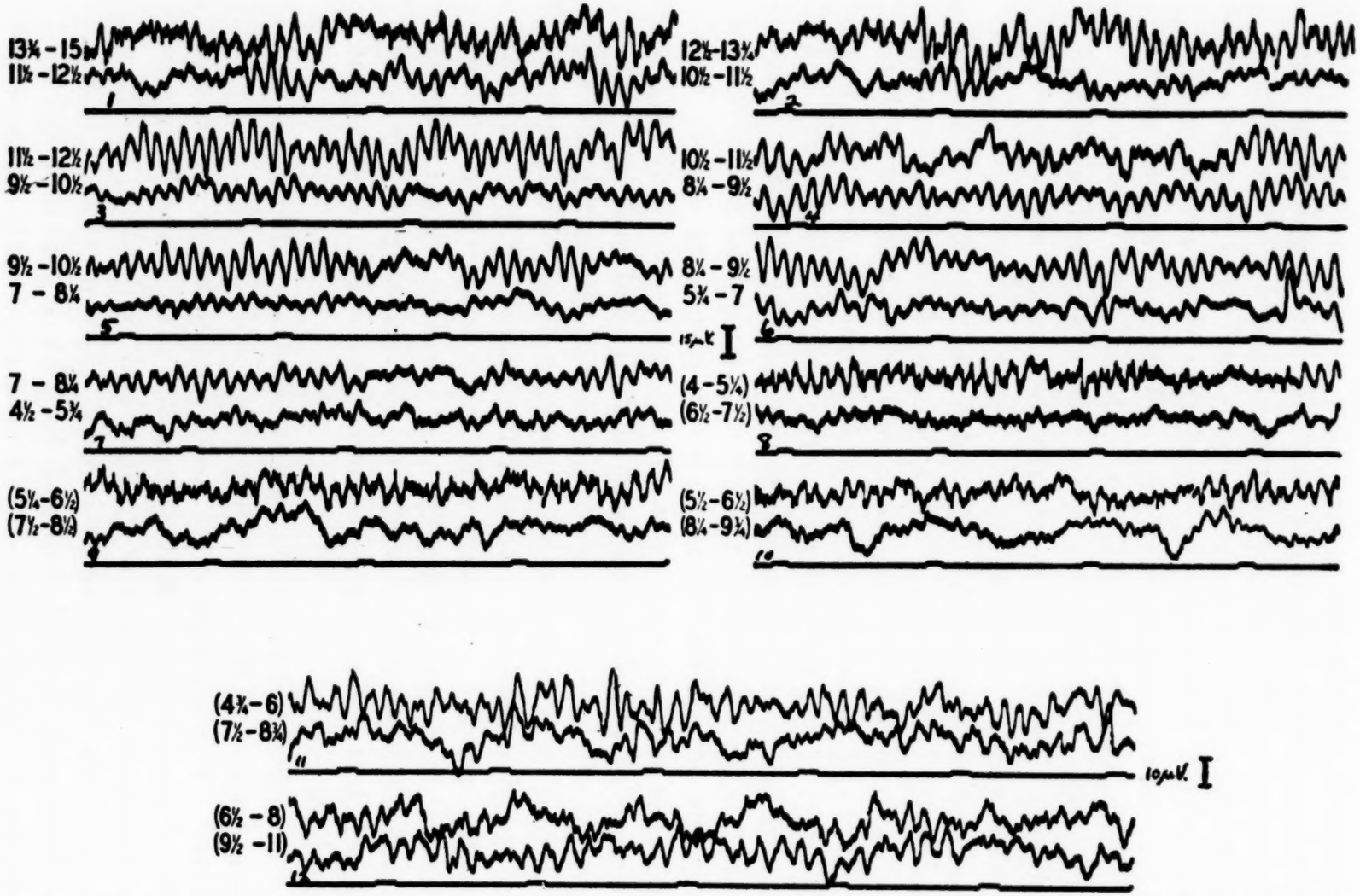

FIG. 3. Records 1 to 10 from longitudinal (records 1 to 7) and horizontal (records 8 to 10) planes of the head in one subject; records 11 to 12 from a horizontal plane in another subject. Foci of activity are indicated by reversals of phase in records 1, 2, 5, 9, and 11.

The lines enclosed by arrows represent the antero-posterior ranges of the four foci of activity for the whole group of subjects. It will be observed that two of the foci lie over regions

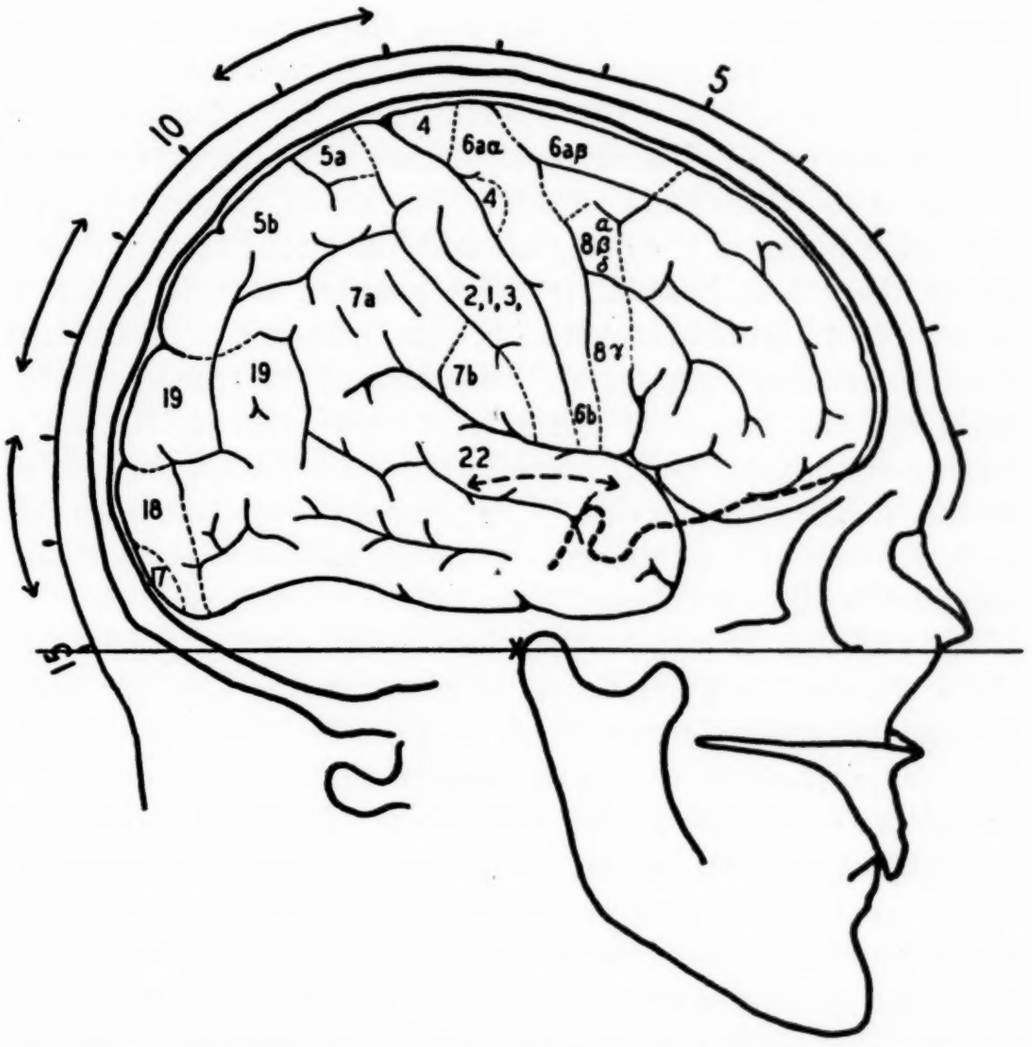

FIG. 4. A tracing of an X-ray photograph of the head of one of the adult subjects. A diagrammatic map of the brain surface adapted from Foerster and Penfield (6), has been fitted to the skull. The distance from the nasion to the inion has been marked off in inches along the mid-line surface contour of the head. Lines enclosed by arrows indicate the antero-posterior ranges of the foci of activity of the alpha rhythm for the whole group of subjects. Positions of the central and parieto-occipital sulci relative to the surface of the head were determined by Chiene's method (5).

which are almost entirely included in the occipital area. One of them, which extends on the surface from 13 to $14\frac{1}{2}$ inches from the nasion, lies chiefly over the parastriate area (Brodmann's area 18). The other ranges from 11 to $12\frac{1}{2}$ inches on

the surface and lies mainly over the peristriate area (Brodmann's area 19). Both of the occipital foci have been fairly well localized between $1\frac{1}{2}$ and $3\frac{1}{2}$ inches from the occipital mid-line. A third focus ranges on the surface from 8 to $9\frac{1}{2}$ inches from the nasion and lies over the anterior part of the parietal area. Its position lateral to the mid-line could not always be localized. The fourth focus is indicated by a broken line enclosed in arrows. It lies in a horizontal plane of the head which cuts through the nasion, anteriorly, and through a point on the occipital mid-line about $1\frac{1}{2}$ to 2 inches above the inion, posteriorly. Its position in this plane is about 6 to $7\frac{1}{2}$ inches from the occipital mid-line. This places it approximately over the auditory area of the temporal lobe. Although the ranges of these focal areas are plotted on a tracing of an X-ray photograph of the head of a subject whose nasion to inion dimension is $14\frac{3}{4}$ inches, they are approximately correct for all subjects since the nasion to inion measurement in all cases ranged from $14\frac{1}{2}$ to 15 inches.

In addition to the localization of foci of activity of the alpha rhythm by the reversal of phase method, it has been pointed out that differences in magnitude of the potentials over the surface of the head suggest that steeper potential gradients exist in the region of the foci. Although in most of the subjects of this group the potentials over the occipital region were larger than elsewhere, there was one subject in whom potentials over the anterior part of the parietal area were consistently greater than over the occipital area. In at least four other subjects the average magnitude of potentials over the anterior part of the parietal area was equal to that of the occipital area (see Figs. 2 and 3). Furthermore there have been definite indications that alpha waves in the region of temporal and parietal foci are of greater magnitude than in the immediately surrounding areas.

Further evidence for a separate origin of alpha waves recorded in different regions of the cortex has been found in records obtained simultaneously from occipital and parietal or temporal areas. Obvious differences in the patterns are frequently noticed and occasionally there may be an interruption or blocking of the rhythm in one area and not in the

other. Sometimes also there are very slight differences in the frequency of the rhythms from such diverse areas, although usually the rhythms from the regions of all four foci are rather closely attuned.

Discussion

The present results strongly suggest, contrary to the views of Adrian and Matthews (1) and Adrian and Yamagiwa (2), that the alpha rhythm originates not only in the occipital region but also in other regions of the cortex. The finding of four separate foci in each cerebral hemisphere (and there may be others in less accessible regions) points to the origin of alpha waves in occipital, parietal and temporal regions. Furthermore, the independent variation of pattern and magnitude of the alpha waves simultaneously recorded in the regions of the various foci, the blocking of the rhythm in one region and not the other, and the slight differences in frequency sometimes observed simultaneously in two of the regions all suggest that there are independent origins of the alpha rhythm. A similar suggestion has appeared in recent studies by Jasper and Andrews (7) and Laugier and Liberson (8), who also found independent variations of the alpha rhythm in different regions as well as indications that the potential gradient is not always steeper in the occipital region than in other regions.

The failure of Adrian and Yamagiwa (2) to find all of the foci of activity reported here may perhaps be due to their method of recording with three electrodes, one of which was common to each of two amplifiers. As was previously stated, this system of recording seems to require almost an exact placement of the common electrode over a focal area in order to reveal a reversal of phase in two records from adjacent areas. In one case where that method was used in this study it failed to reveal a single focus of activity in a series of electrode placements in a longitudinal plane, whereas a subsequent series of records with the electrodes in slightly different positions in the same plane revealed clearly the two occipital foci.

The fact that there appear to be two distinct foci in the occipital region may account for the greater magnitude of

potentials usually found there. It may also account for what Adrian and Yamagiwa (2) considered a rather widespread shifting of a single focus in the occipital region. Certainly there is no evidence that the foci here reported over the anterior part of the parietal area and the temporal region are due to the shifting of an occipital focus.

Since the foci of activity of the alpha rhythm are found over the visual, common sensory, and auditory fields it suggests that they may have something to do with the projection of thalamo-cortical pathways. It is possible that 'cöordinating circuits' from thalamus to cortex, for which Bishop (4) and his collaborators have found evidence in connection with the visual processes in the rabbit, are involved. In other words, if, as their work seems to imply, thalamo-cortical 'coördinating circuits' condition the excitability of the visual cortex and are associated with the 'spontaneous' rhythms found there, perhaps similar circuits are to be found in other sensory areas.

Although alpha potentials probably represent the summation of relatively synchronous discharges in large numbers of cortical cells, the evidence presented by Bishop (4) suggests that thalamo-cortical mechanisms control the rhythm of the discharge. In this light one might think of the foci in the various sensory areas as points of initiation of control. That is, the 'coördinating circuits' impinging on these areas may rhythmically initiate discharge in a limited group of cells, the excitation being transmitted more or less equally in all directions to other cells in the immediate neighborhood.

Although there is no direct anatomical evidence for the above hypothesis at present, it is of interest that a recent study by Le Gros Clark and Northfield (9) has called attention to hitherto undescribed pathways from the pulvinar to the periparastriate areas (Brodmann's areas 18 and 19), for which no specific function has yet been demonstrated. Pathways from the pulvinar to the parietal and temporal regions have also previously been described. It may be that these or other thalamo-cortical pathways serve as 'coördinating circuits' and that their cortical projections are indicated by the so-called foci of activity of the alpha rhythm.

Summary

By means of two matched amplifying and recording systems brain potentials have been recorded simultaneously from adjacent areas along longitudinal and horizontal planes of the head in 16 subjects. Study of the phase relationships of the alpha waves from adjacent areas has revealed four separate foci of activity of the alpha rhythm in each cerebral hemisphere. Two of the foci are located over the occipital region of the brain, a third over the anterior part of the parietal area and a fourth over the temporal region. In addition to the phase relationships, other evidences of multiple foci have been found, such as independent variations in the pattern, magnitude and frequency of the alpha waves recorded from different regions of the brain. This indicates that the alpha rhythm of each region has a separate origin. The foci of activity have been discussed and the suggestion made that they may be associated with thalamo-cortical projections which exercise a controlling influence on the 'spontaneous' rhythms of the cortex.

(Manuscript received March 10, 1938)

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EXPERIMENTAL STUDIES IN ROTE-LEARNING THEORY. III. DISTRIBUTION OF PRACTICE WITH VARYING SPEEDS OF SYLLABLE PRESENTATION

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INTRODUCTION

An increase in the interval of time between successive syllables in the learning of serial lists greatly reduces intra-serial interference effects. This is indicated by a change in the distribution of errors in the several serial positions (Hovland, **14**) and by a reduction in the number of trials required for learning (*cf. e.g.* Gamble, **8**). Associated with this decrease in intra-serial interference is a diminution of reminiscence (Hovland, **14**). Now if distribution of practice is effective because it utilizes the reminiscence effect (**2**), and if slow rates of syllable presentation decrease reminiscence, we should expect that the efficacy of distributed practice would be much less with slow than with rapid rates of syllable presentation. This deduction was tested in the present experiment. In addition, the data obtained permit comparison of two distinct methods of distribution of effort. Customarily the term 'distribution of practice' is restricted to mean the introduction of an interval of time between successive presentations of the entire list of syllables. The efficacy of this method will be compared to that obtained when the time interval is increased between the successive syllables in the serial lists.

[1] This is the third article in a series of studies by the writer on the investigation of experimental implications of a mathematico-deductive theory of rote-learning developed in a forthcoming monograph by Hull, Ross, Perkins, and Hovland (**20**). (See **10**, **13** and **14**.)

The writer wishes to express his thanks to Professor Clark L. Hull for encouragement of the work, and to Professor Donald G. Marquis for critical reading of the manuscript.

Experimental Procedure

The subjects learned 12-unit lists of nonsense syllables to mastery by massed and by distributed practice with two speeds of syllable presentation, a two-second and a four-second rate. For the massed practice only six seconds elapsed between successive presentations of the lists. For the distributed practice a rest pause of two minutes and six seconds was interposed between trials. This interval has been shown to be a favorable one for the occurrence of reminiscence with the two-second presentation rate (14, 34).

Four experimental programs of learning were employed:

I. Learning by *massed practice* with *two-second* rate of syllable presentation.
II. Learning by *distributed practice* with *two-second* rate of syllable presentation.
III. Learning by *massed practice* with *four-second* rate of syllable presentation.
IV. Learning by *distributed practice* with *four-second* rate of syllable presentation.

The criterion of mastery was one perfect recitation of the list. During the rest period of two minutes and six seconds between successive presentations of the lists by distributed practice, color-naming was introduced to obviate rehearsal.

Two cycles of each of the above four programs were learned in counter-balanced practice order. The method and instructions were the same as those used in the earlier studies in the series (13, 14). This procedure involves learning to anticipate, by pronouncing, three-letter nonsense syllables presented automatically in the Hull exposure apparatus (19). All the experiments were conducted in a sound-proof chamber to reduce distractions.

Eight experimental and two practice lists were prepared. Each list contained twelve syllables and a cue symbol. The lists were prepared to insure comparability with respect to associational value, and were systematically rotated so that different subjects began with different portions of the series.

Each program was represented equally in each position of practice during learning.

The subjects were Yale College students who were paid for their services. Since the 32 subjects employed in this experiment had worked previously in memory experiments of the writer, only two practice periods were required. The subjects reported at the same hour every day except Sunday for the duration of the experiment. They were not informed in advance as to which of the four experimental programs would be employed.

Results

The average numbers of trials required to reach the criterion of one perfect recitation by the four learning procedures are given in Table 1. Distributed practice is clearly superior to massed when the learning has been at the two-second rate of presentation (C.R.$_{\sigma}$ = 3.53). With the slower rate of presentation, however, the advantage of distributed practice is much less marked, and the reduction in number of trials is not statistically reliable (C.R.$_{\sigma}$ = 1.21).

TABLE 1

MEAN NUMBER OF TRIALS REQUIRED FOR LEARNING BY MASSED AND BY DISTRIBUTED PRACTICE AT TWO RATES OF SYLLABLE PRESENTATION (32 SUBJECTS)

	Mean	σ_M
Two-second rate of presentation		
Trials required by massed practice	14.89	0.93
Trials required by distributed practice	11.18	0.87
Difference	3.71	
σ_{diff}	1.05	
C.R.$_\sigma$	3.53	
Four-second rate of presentation		
Trials required by massed practice	6.78	0.56
Trials required by distributed practice	5.85	0.54
Difference	0.93	
σ_{diff}	0.77	
C.R.$_\sigma$	1.21	

Table 2 gives the percentage of matched trials in which massed or distributed practice is superior. Trials involving different experimental procedures but representing the same amount of preceding practice were paired for each subject. In 68 percent of the matched trials the learning by distributed practice was superior to the massed at the two-second rate. The advantage was smaller at the four-second speed, but still noticeable.

TABLE 2

PERCENTAGE OF PAIRED TRIALS SHOWING SUPERIORITY OF MASSED OR DISTRIBUTED PRACTICE WITH TWO RATES OF SYLLABLE PRESENTATION (64 PAIRED TRIALS)

	Percent	σ_P
Two-second rate of presentation		
1. Distributed practice superior to massed	68.8	.058
2. Massed and distributed practice equally efficient	10.9	.039
3. Massed practice superior to distributed	20.3	.050
Difference in percent between 1 and 3	48.5	
Four-second rate of presentation		
1. Distributed practice superior to massed	48.4	.063
2. Massed and distributed practice equally efficient	26.6	.055
3. Massed practice superior to distributed	25.0	.055
Difference in percent between 1 and 3	23.4	

TABLE 3

PERCENTAGE OF SUBJECTS LEARNING MORE RAPIDLY BY MASSED OR BY DISTRIBUTED PRACTICE AT TWO RATES OF SYLLABLE PRESENTATION (32 SUBJECTS)

	Percent	σ_p
Two-second rate of presentation		
1. Subjects learning more rapidly with distributed practice	71.9	.080
2. Subjects learning equally rapidly with massed and with distributed practice	9.4	.051
3. Subjects learning more rapidly with massed practice	18.7	.068
Difference in percent between 1 and 3	53.2	
Four-second rate of presentation		
1. Subjects learning more rapidly with distributed practice	56.2	.088
2. Subjects learning equally rapidly with massed and with distributed practice	21.9	.073
3. Subjects learning more rapidly with massed practice	21.9	.073
Difference in percent between 1 and 3	34.3	

In Table 3 results are presented in terms of the number of subjects who showed faster learning under massed and distributed practice. Here, it will be observed, 72 percent of the subjects learned more rapidly by distributed practice than by massed at the two-second rate, while at the four-second rate only 56 percent learned more rapidly by distributed practice.

The relative advantages of massed and distributed practice at the two speeds of presentation can be seen most clearly from the figures. In Fig. 1 the number of trials required to reach each of the syllable criteria are presented for massed and distributed practice with the two-second and the four-second rates of presentation. These figures show the learning by massed practice at the two-second rate to be of the customary negatively accelerated type (Melton, **27**). Distributed practice with the two-second rate of presentation serves to decrease the negative acceleration in the learning. Thus the disparity between the number of trials to learn to comparable criteria by massed and by distributed practice increases throughout the learning. The massed practice at the four-second rate, on the other hand, shows very little negative acceleration, and the line for distributed practice

diverges less from it. The numerical values for Fig. 1 are given in Table 4.

From these results it appears that the amount of advantage of distributed practice is more closely related to the number

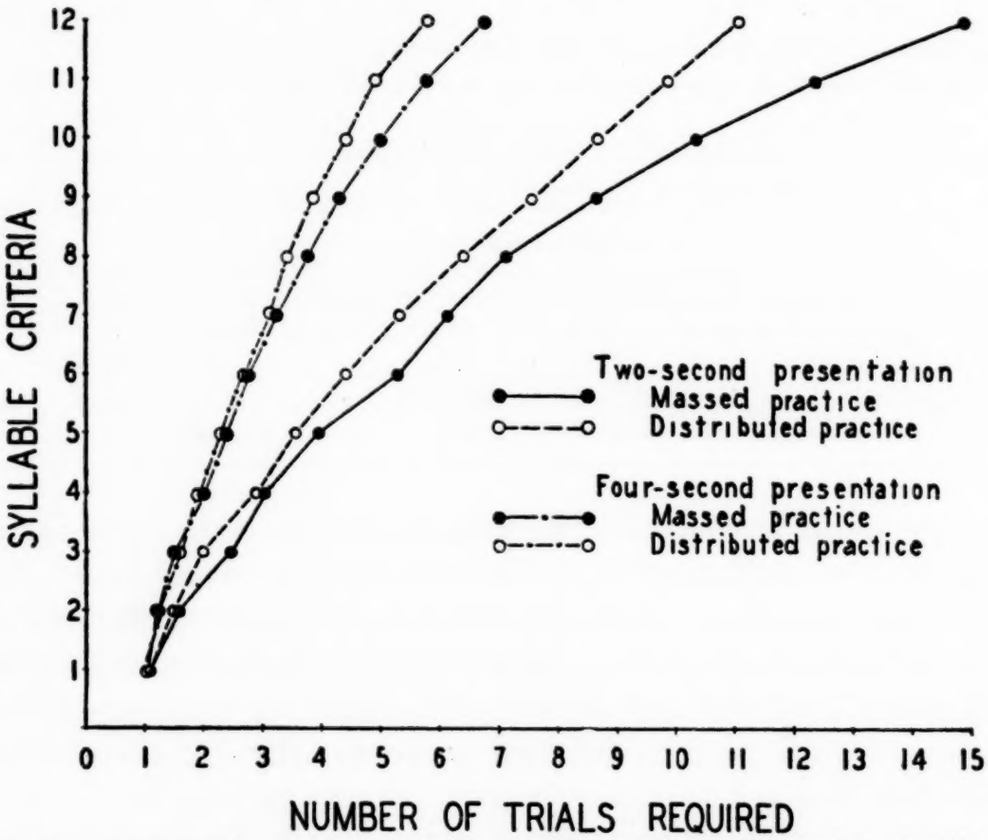

FIG. 1. Learning curves. Composite graphs showing mean number of trials to reach successive criteria of performance by massed and by distributed practice with two-second and with four-second rates of presentation. Each point based upon the mean of 64 learning scores.

TABLE 4

AVERAGE NUMBER OF TRIALS TO REACH SUCCESSIVE CRITERIA OF PERFORMANCE BY MASSED AND DISTRIBUTED PRACTICE AT TWO-SECOND AND AT FOUR-SECOND RATES OF PRESENTATION. MEANS BASED UPON 64 LEARNING SCORES FOR EACH CONDITION

	Criteria of Performance (Syllables Correct)											
	1	2	3	4	5	6	7	8	9	10	11	12
Two-second rate												
Massed practice.....	1.18	1.55	2.46	3.04	3.96	5.27	6.19	7.20	8.69	10.38	12.41	14.89
Distributed practice..	1.09	1.48	2.01	2.83	3.59	4.41	5.32	6.47	7.61	8.73	9.88	11.18
Four-second rate												
Massed practice.....	1.06	1.25	1.53	1.97	2.39	2.75	3.22	3.78	4.38	5.00	5.78	6.78
Distributed practice..	1.09	1.28	1.60	1.86	2.28	2.70	3.16	3.41	3.81	4.47	4.94	5.85

of trials involved in learning to a given level of performance than to the degree of learning itself. That is, there is a difference of about one trial in the number of trials required to reach mastery by massed and distributed practice at the four-second rate of presentation, whereas the difference in number of trials to reach mastery by massed and distributed practice with the two-second rate is between three and four. But in the former case less than six trials were required for learning by distributed practice, while in the latter over eleven were required. The amount of difference between massed and distributed practice when six trials have been spent in the learning by distributed practice at the two-second rate will be observed to be about the same as that obtained when six trials have been spent in learning at the four-second rate.

From the data presented it is also apparent that learning is much more rapid at the four-second than at the two-second rate of presentation by massed practice. An advantage is clearly shown at every criterion of learning. This confirms the findings obtained by the writer (**14**) and previous investigators cited by him. Similar results with other methods of learning are presented by Ruschel (**30**).

In Fig. 2 the mean number of failures is given for each syllable position with learning by massed and distributed practice at the two rates of syllable presentation. For both massed and distributed practice there is the usual accumulation of difficulty in the central portion of the list, but the difficulty is much reduced by distributed practice. The discrepancy between the curves representing the learning by massed and by distributed practice is most marked in the central portions, and least in the end positions. This confirms results presented by Patten (**29**). The difficulty of learning is reduced markedly for each syllable position with the slower rate of presentation, but the absolute differences between the learning by massed and distributed practice are much smaller than those involved in learning by the two methods at the two-second rate. Table 5 contains the numerical data from which Fig. 2 was drawn.

An interesting difference between the two and four-second

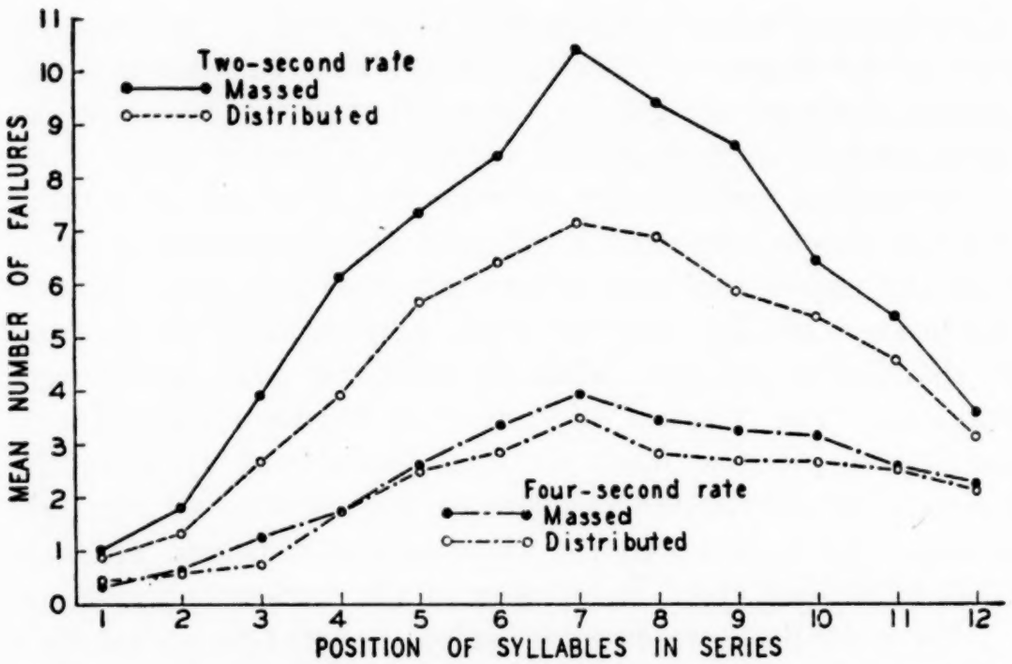

FIG. 2. Composite curves showing mean number of failures in various syllable positions involved in learning to mastery by massed and by distributed practice with two-second and with four-second rates of presentation. Each point based upon the mean of 64 learning scores. Failures are computed beginning with the first trial on which the subjects attempt recall, *i.e.*, the second rotation of the drum.

rate of presentation is revealed in the oscillations at the threshold of recall. Hull (**18**) has shown that subjects will frequently respond successfully one or more times at a point in a rote series, and then fail at that particular syllable before another success occurs. Such a sequence of successes and

TABLE 5

MEAN NUMBER OF FAILURES TO RESPOND CORRECTLY IN THE DIFFERENT SYLLABLE POSITIONS DURING LEARNING TO MASTERY BY MASSED AND DISTRIBUTED PRACTICE WITH TWO-SECOND AND FOUR-SECOND RATES OF PRESENTATION. EACH MEAN BASED UPON 64 LEARNING SCORES

	Position of Syllable in Series											
	1	2	3	4	5	6	7	8	9	10	11	12
Two-second rate												
Massed practice.....	1.05	1.77	3.86	6.15	7.36	8.40	10.45	9.41	8.60	6.45	5.41	3.61
Distributed practice..	0.96	1.31	2.74	3.90	5.75	6.48	7.23	6.87	5.81	5.32	4.67	3.24
Four-second rate												
Massed practice.....	0.31	0.65	1.28	1.78	2.59	3.34	3.94	3.47	3.25	3.15	2.56	2.28
Distributed practice..	0.44	0.59	0.75	1.78	2.50	2.84	3.50	2.81	2.69	2.65	2.50	2.09

failures he has called an 'oscillatory cycle' at the threshold of recall. From the first success to the last failure constitutes the entire range of the oscillations. In Fig. 3 a graph is

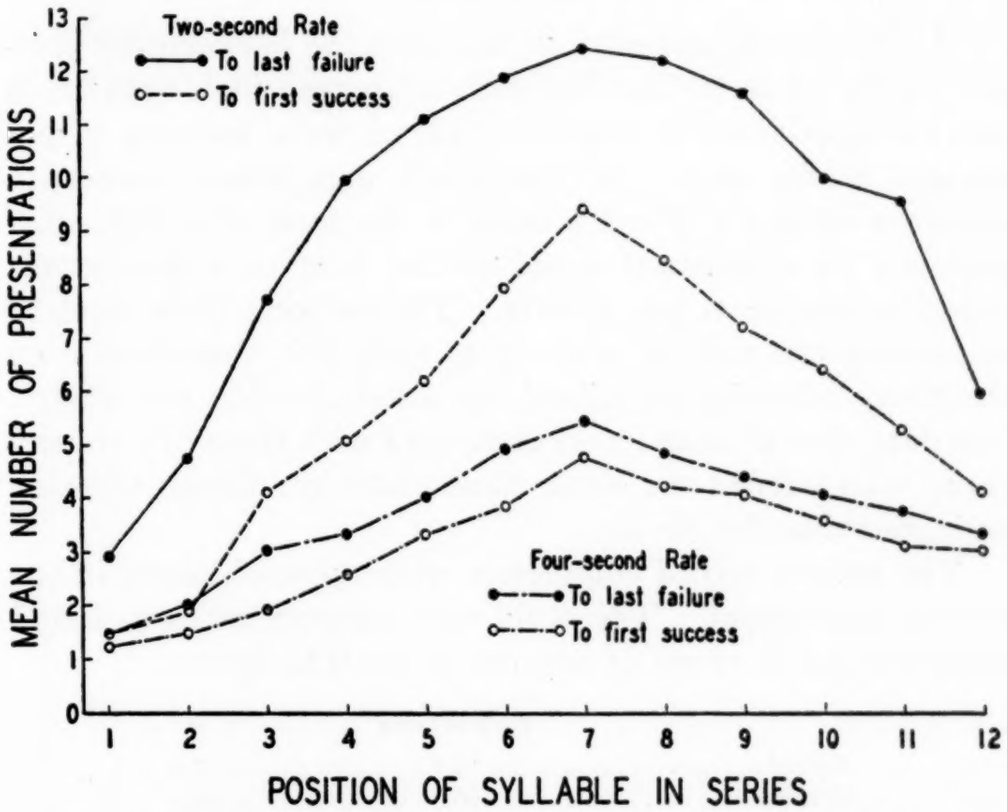

FIG. 3. 'Oscillations' at the threshold of recall. Composite curves showing mean number of presentations preceding first correct response and last failure for syllables in each position for learning at two-second and at four-second rates by massed practice. Each point based upon mean of 64 learning scores.

presented showing the number of exposures of each syllable preceding (*a*) the first success, and (*b*) the last failure in the learning. As is to be expected because of the more rapid speed of learning with the four-second presentation, it will be seen that the first success is reached more rapidly at the four-second than at the two-second rate of presentation in every syllable position, and that the learning is completed much more rapidly at this rate (as indicated by the fewer number of trials preceding the last failure). Also to be expected is the conspicuous fact that the range of oscillation between the first success and the last failure is much smaller for the four-second than for the two-second rates when both have been

by massed practice. The range of the oscillations appears to be a good additional index of the amount of interference involved in the learning.

Discussion

An interesting comparison can be made between the present results on serial learning with nonsense syllable materials and an experiment by Husband (**22**) on serial learning with a manual motor task. In Husband's experiment university students learned a Warden maze in the form of a high relief pathway at a constant speed to the beat of a metronome sounding 100 beats per minute. The subjects were required to traverse one unit of pathway to each tick, thus decreasing the time ordinarily permitted for discrimination and choice. The data thus obtained were compared with those of a control group who learned the same maze under conditions allowing unlimited time for choice.

The results accord completely with those obtained in the present experiment. The rapid rate (metronome) was found uneconomical in terms of number of trials to learn:

	Trials to Learn	σ
Control	16.7	7.5
Metronome	26.8	12.5

Husband likewise reports that the "learning curves for the two groups are . . . similar to each other, that for the control group always being lower" (p. 368). As in the present experiment the difference between the groups becomes more pronounced late in the learning.

Further interesting parallels are afforded by comparison of the error distributions at the two speeds. The table below is reproduced from Husband and gives the errors on the different blinds and the direction of correct choice. With this

	Total Errors on Each Blind									
	1 R	3 L	5 L	7 L	9 R	11 R	13 L	15 R	17 R	19 L
Control	53	25	105	165	27	83	85	46	148	38
Metronome	49	23	120	259	25	188	162	53	223	59

type of maze it is extremely difficult to determine the errors in the various portions of the maze without complications such as the tendency for a piling-up of errors in sequences of like choices. For the present analysis, however, it is perhaps justifiable to pool the errors in the first, middle and last thirds of the maze under the two conditions. In Fig. 4 these results

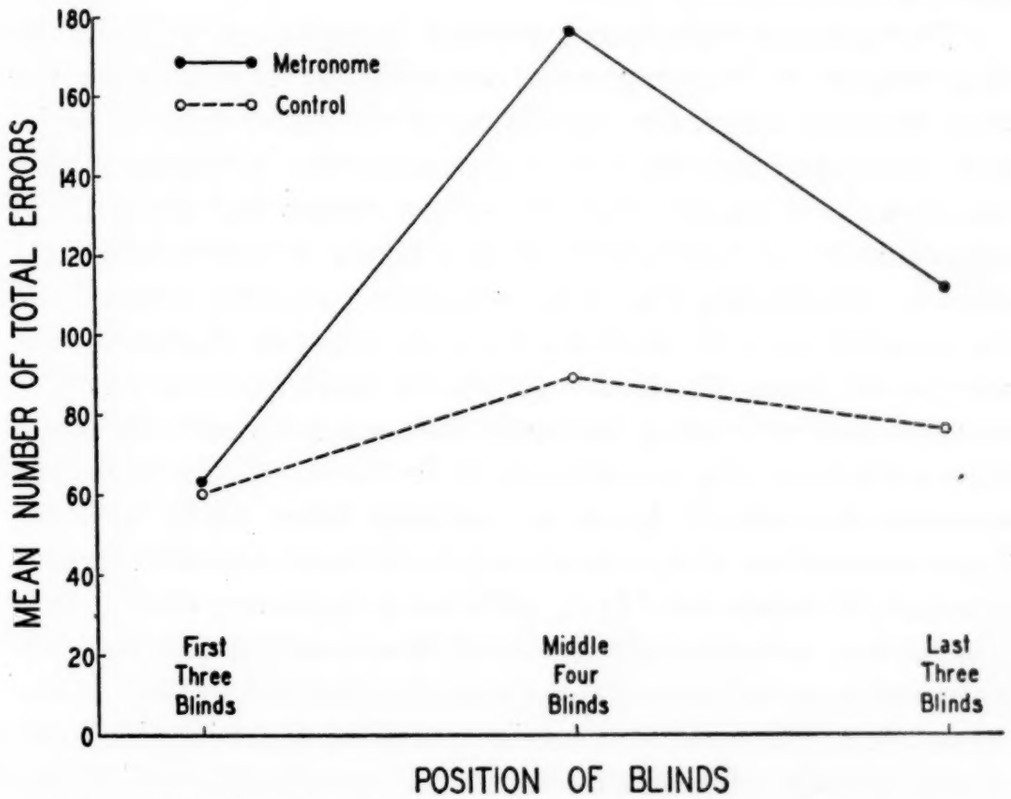

FIG. 4. Mean number of total failures per blind made in various portions of Warden maze learned either to a metronome beat of 100 per minute or with unlimited time. Data from Husband (22).

are presented showing the average number of total errors in the first three, the middle four, and the final three blinds for the control and metronome groups. Comparison of these results with those presented for verbal learning in Fig. 2 shows the following interesting similarities: (1) The accumulation of errors in the central portion of the maze; (2) the greater difficulty of the terminal blinds as compared with the initial ones; (3) the increased number of errors at the more rapid rate of learning; (4) the slight increase in difficulty of the initial portions of the maze with the more rapid rate; (5) the

more marked increase in the difficulty of the terminal portion with the more rapid rate; and (6) the extremely pronounced increase in the difficulty of the central portions with the learning at the rapid rate. Interesting experiments are suggested by these results in determining the amount of reminiscence and the efficiency of distributed practice under control and metronome conditions.

The present experiment permits comparison of the relative efficacy in learning serial associations of increasing the time between successive repetition of the entire syllable series and increasing the time between successive syllables within the series. With the time intervals chosen for the present experiment the superiority of the latter is overwhelmingly shown. Increasing the time between successive trials from six seconds to two minutes and six seconds decreases the number of trials required to learn to mastery from 14.89 to 11.18, while increasing the time between successive syllables within the list from two seconds to four seconds decreases the number of trials to learn to mastery from 14.89 to 6.78. Experimentation with a wide variety of other combinations of intervals is indicated. It is, of course, apparent that such a comparison is valid only if one is interested in the rapidity with which serial associations may be learned. The results cannot be applied without further study to tasks in which one of the criteria of performance is the speed with which the serial actions may be performed, since in the present experiment the final recitation at complete learning takes place at different speeds.

The learning curves presented in Fig. 1 show in a very clear way the operation of the interference factors in learning. The relative linearity of the curve for the four-second rate provides an interesting contrast to the negative acceleration of the two-second curve when learning has been by massed practice in both cases. These results suggest that with ideal distribution between units of the series and between successive presentations of the series the learning curve for this type of material would be completely linear. It is further suggested that the performance by distributed practice represents the

upper limit of the envelope of values within which single rest pauses will be effective in producing improvement in the typical reminiscence experiment.

Few theories attempting to explain the efficacy of distribution of practice have been formulated in a sufficiently precise and rigorous way to permit critical test of their adequacy. The results obtained in the present experiment are not, therefore, crucial for theories of distributed practice. In a general way the data are in support of the hypothesis advanced by Bunch and Magdsick (**2**), inasmuch as they show that factors which decrease reminiscence likewise decrease the efficiency of distributed practice. Additional experiments of the writer support this generalization (**12**, **15**, **16** and **17**). Reminiscence has, in turn, been shown to be intimately related to the factors producing an accumulation of difficulty in the central portions of the serial lists (**13**, **14**). It by no means follows, however, that the factors causing reminiscence are the only ones involved in distributed practice efficiency. Brief discussion of the general theories of distributed practice seems therefore indicated:

(1) *Perseveration.*—According to Müller and Pilzecker's (**28**) hypothesis the neural processes perseverate for a considerable time following learning. Distributed practice permits the setting-in process to proceed with minimal interference. To explain the present results where marked advantage of distributed practice was found with rapid presentation of the syllable, but little advantage with the slow rate, one would have to assume that the perseveration is greater following the two-second than following the four-second rate of syllable presentation. Experimental refutation of this point is suggested in the study of Gamble (**8**).

(2) *Rehearsal.*—This factor was ruled out as an explanation by the introduction of color-naming during the rest pause, thus forestalling Lashley's (**24**) criticism that with "verbal habits the possibility of practice outside of the experimental practice periods has not been altogether eliminated where short practice periods were used" (p. 366). Without subsidiary hypotheses rehearsal would not explain the difference

in amount of improvement resulting from distributed practice at the two rates of syllable presentation.

(3) *Fatigue.*—The advantage of distributed practice is frequently the result of dissipation of fatigue effects (**9**). If one restricts the term 'fatigue' to physical fatigue and does not make it synonymous with any type of decremental factor in learning, this theory may be tested crucially. If more fatigue is involved at the more rapid rate of presentation the advantage of distribution of practice should be greater. But Curtis (**3**) has already tested the amount of subjective and measurable fatigue involved in learning at slow and at rapid rates of presentation. Her results fail to show that more fatigue is involved in learning with more rapid presentation. Hence there would be no reason to expect greater advantage of distributed practice with the two-second than with the four-second speed.

(4) *Motivation.*—Motivation may frequently be a factor in explaining the efficacy of distribution of practice (**4**), but the present experiment sheds no light on this theoretical formulation. There is no evidence that the motivational factors are different in the learning at the two speeds of syllable presentation.

(5) *Refractory Phase.*—It has been experimentally shown that associative responses demonstrate many of the characteristics of refractory phase (**5, 33**), although the evidence is far from incontrovertible. Repetition of a response at short intervals produces marked decrement in the response. It is highly probable that some such factor is involved in the explanation of the greater rapidity of learning by the slower rate of presentation. To explain the fact that distributed practice is more effective with the two-second than with the four-second rate the additional hypothesis of cumulative refractory-phase effects would be required. There is considerable evidence for cumulative refractory effects at the neurophysiological level [2] but little at the level of associative processes. Research directed at the study of possible cumula-

[2] *Cf.* FORBES, A. The mechanism of reaction. Chapt. 3 in *Handbook of Gener. Exper. Psychol.* (C. Murchison, edit.). Worcester, (Mass.): Clark Univ. Press, 1934, pp. 155–203.

tive refractory phase effects in associative responses would help materially in testing this explanation of distribution of practice results.

(6) *Recall of Incompletely Learned Tasks.*—The fact that interrupted tasks are better remembered than uninterrupted ones (Zeigarnik, **36**) has been used as an explanation of distributed practice efficiency (**1**). At present, however, we do not know the explanation of the Zeigarnik effect itself. It is quite possible that this phenomenon will ultimately have its explanation in terms of one of the other theories here discussed. Until this phenomenon has been itself satisfactorily explained, therefore, it will be of little help in explaining results on distributed practice.

(7) *Age of Associations.*—Jost's (**23**) hypothesis that a new repetition strengthens an older more than a younger association of equal age might be applied in the present case. The age differences between massed and distributed practice associations are very slight with the four-second presentation rate because the learning is so rapid, but the differences are quite marked when the two-second rate of presentation is employed and a large number of learning trials are involved. In support of this theory is the fact previously mentioned that the advantage of distributed practice seems more closely related to the number of trials preceding the performance than to the criterion of performance reached. Other subsidiary principles would then be required to explain why learning is more rapid with the four-second than with the two-second rate of presentation, since age differences would not explain this result.

(8) *Maturation.*—Distributed practice permits the development of the maturation process induced by stimulation. Wheeler and Perkins' (**35**) theory has been recently reformulated by Doré and Hilgard (**6**) to explain distributed-practice efficacy in pursuit learning: "At any given age-maturational level, the optimum rate of stimulation to secure improvement in a given function depends upon the normal rate of stimulation-induced maturation in that function" (p. 246). The present experiment alone is not crucial with respect to this

theory, but taken together with other experiments of the writer casts some doubt upon the generality of the hypothesis. Discussion of this hypothesis will consequently be reserved for a later article in the series. Closely related is Snoddy's (**32**) concept of two opposed processes in learning, the first of which is a positive function of time. The present observations showing that the advantage of distributed practice becomes more marked with higher criteria of learning are opposed to Snoddy's results (**31**) but agree with those of Lorge (**25**).

(9) *Dropping Out of Wrong Associations.*—"The rest intervals may provide an opportunity for the dropping out or forgetting of wrong associations" which are "less strongly formed than the right ones and hence are forgotten more rapidly" (McGeoch, **1**, p. 322). The advantage of this explanation in explaining distribution of effort efficacy is stressed by Easley (**7**). This type of explanation seemed to the writer (**13**) and to Ward (**34**) the most adequate one in explaining reminiscence phenomena. The same conceptualization may be parsimoniously applied to the present results. With slower speeds of presentation the interference effects are reduced (**14**), wrong associations decreased, and consequently the differential between the efficiency obtained by massed and distributed practice is decreased.[3]

This brief survey of the conflicting theories attempting to explain the efficiency of distributed practice strongly supports the contention of Hunter (**21**), Guthrie (**9**) and others as rephrased by McGeoch (**1**): "No single factor which will account for them [the results on distribution of practice] has been found, and it is probable that they are determined by a group of conditions, not all of which need to be operating in every case" (p. 322). Additional work on the problem

[3] A more general formulation of this theoretical position would involve the concepts of two competing processes in learning. The effective learning would be the algebraic sum of the two antagonistic effects. But if the interfering or "inhibitory" process, because of its lesser strength, declines more rapidly than the positive learning process with the passage of time, an initial increase in effective strength would be obtained. This would be the reminiscence phenomenon. Distribution of practice would then be effective because it utilizes successive reminiscence effects. The testing at the conditioned response level of some of the deductions obtained from such an analysis has been attempted by Hovland (**11**).

with attempts to isolate the various factors involved in the advantage of distributed practice is clearly indicated.

Summary and Conclusions

1. Thirty-two college students learned lists of twelve nonsense syllables by the anticipation method with massed and distributed practice at both a two-second and a four-second rate of syllable presentation. During distributed practice a two-minute period of color-naming was interpolated between successive trials.

2. In confirmation of the results previously reported by the writer and others, fewer trials were required for learning by massed practice with the four-second than with the two-second rate of presentation.

3. Distribution of practice was very effective in reducing the mean number of trials for learning at the two-second rate of presentation. Seventy-two percent of the subjects learned more rapidly by distributed than by massed practice.

4. The advantage of the distributed practice over the massed was most apparent in the central portion of the serial lists.

5. Distribution of practice was much less effective with the four-second rate than with the two-second rate of presentation, although distributed practice was still superior to massed. With the four-second rate only 56 percent of the subjects learned more rapidly with distributed than with massed practice.

6. The magnitude of the difference between the number of failures at the two-second and at the four-second rate was greatest in the central serial positions.

7. The negative acceleration in the learning by massed practice was very pronounced at the two-second rate, but was reduced when the learning was at the four-second speed. Increasing the time either between successive trials or between successive syllables decreased the rate of negative acceleration. With the combination of intervals chosen for this experiment the latter method appeared much more effective in decreasing the number of trials required for learning, although exact

comparability was not obtained since the performance was not identical.

8. Comparison of the results with the two-second and four-second rates of presentation suggests that the amount of advantage of distributed practice is more closely related to the number of trials preceding learning to a given level of performance than to the degree of learning itself.

9. Records were kept of the 'oscillations' at the threshold of recall. Under conditions of massed practice the band of the oscillation between the first success and the last failure for the several serial positions was much wider with the two-second than with the four-second rate. This suggests its use as an additional index of the amount of interference involved in the learning.

10. The phenomena obtained in the present experiment with serial learning of verbal materials are strikingly paralleled by the results obtained by Husband in the learning of a serial motor task by college students.[6]

11. The theoretical implications of the present results are discussed and the most common theories of distributed practice reviewed and criticized.

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ON THE PSYCHOPHYSICS OF TASTE. I. PRESSURE AND AREA AS VARIANTS

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Although taste is usually regarded as a chemical sense (**2, 4, 8, 11, 12**) a comprehensive survey of the literature (**13**) reveals in striking fashion the need for more quantitative information before the significance of the chemical reactions involved in gustatory reception can be profitably evaluated.[1] However, the contribution of *neurophysiological* processes which take place during the act of tasting can at present be considered with profit. The technique of the simple reaction, for example, seems to provide an excellent means for the study of gustatory functions in terms that are meaningful from the standpoint of neurophysiological fact. Thus we have undertaken to determine the manner in which gustatory reaction-times to saline solutions for human subjects vary as a function of neurophysiologically significant variables. In the present experiment, the temperature and concentration of the stimulating solution were held constant: and, under specially controlled conditions, gustatory reaction-times were measured as the pressure of the taste solution at the surface of the tongue and as the area of stimulated surface (and hence the number of nerve-fibers potentially available for excitation) were made to vary.

Method and general procedure.—Measurements of the simple sensory reaction-times to a saline solution (NaCl) for pressure as variant were made in the following manner. A graduated, cylindrical glass tube (*ID* = 0.3 cm.) was used as pipette and filled with the solution to one of five predetermined heights. The outside surface of the tube was wiped dry with a clean towel; a single stroke downward usually sufficed to dry the tube and also to render concave the exposed surface of the liquid at the bottom of the pipette. When appropriately loaded, the tube was placed and maintained in a vertical

[1] The most suggestive research has been carried out upon lower organisms (**2, 5**); but, even there, the theoretical interpretation frequently suffers from the lack of data which are chemically univocal (**6, 7, 9**).

position at the tongue with the aid of suitable guides which were fixed to a rack-and-pinion mounted on a heavy standard. The observer, blindfolded, with chin resting on an adjustable support and with his right hand in contact with the lever for releasing the clutch of a Cenco-Harrington timing device, protruded his tongue at a given signal. The experimenter then lowered the tube so that the exposed surface of the solution just covered the region selected for stimulation, removed his finger from the top of the tube (thus permitting the liquid to exert its pressure upon the test area). At the same time, the observer set the timer into operation. Immediately following the perception of the salt-taste, the observer stopped the timer.

The temporal interval elapsing between the onset of the stimulus and final response was recorded by the experimenter while the observer washed his tongue and rinsed his mouth with tap water. At least three minutes elapsed between successive stimulations. One minute before each stimulation, the mouth was filled with distilled water at a temperature equal to that of the NaCl-solution ($= 18° \pm C$); the mouth was then emptied and the test-region of the tongue was dried with a fresh sample of blotting paper. This entire procedure was carried out five times for each of the pressures used. The same region of the tongue (about 2 cm. from the tip in the median plane) was stimulated in all cases. The observers were set by instruction to react only upon the perception of a salt-taste.

In order to increase the number of the taste-cells *available for reaction* with the stimulating solution (thus also increasing the number of gustatory nerve fibers potentially available for excitation), another tube ($ID = 0.8$ cm.) was employed.[2] The same pressures were exerted as for the first tube and the same region of the tongue was stimulated. The surface of the tongue exposed to the action of the solution in the second tube, however, was more than seven times as great as (and included) the surface exposed to the solution presented by the first.

Results.—The data for two practiced observers (the writers) are presented in Table I. Each entry (in secs.) is an average of five measurements; with each average is associated the standard deviation of a single observation. For A. H. H., the concentration used was 0.5 mole per liter; for L. M. H., 1.0 mole per liter. These results constitute an experimental demonstration (a) that the time required for a simple gustatory reaction varies inversely with the pressure exerted by the stimulating solution and (b) that the gustatory reaction-time decreases as the number of taste-cells available for the reaction is made to increase.

Theory.—An increase in the pressure exerted by the stimulating solution under the conditions of this experiment can

[2] In construction, these glass cylinders were drawn and cut so as to produce the same mechanical pressure. The hydrostatic pressures actually exerted upon the surface of the tongue by the solutions were measured *in situ* with a sensitive manometer. P is expressed in units that are directly proportional to the conventional c-g-s standard (dynes/cm^2).

give rise to at least two different effects at the receptors. The first is mechanical in nature. The second depends upon the first but is chemical in nature. Each, however, leads ultimately to the same theoretical expectation: a decrease in the time required for the excitation of a single taste-cell. We may consider the mechanics of the situation first; the chemistry, next.

TABLE I

SIMPLE GUSTATORY REACTION-TIMES TO NaCl-SOLUTIONS WITH PRESSURE AND AREA AS VARIANTS FOR TWO OBSERVERS

Each entry is based on 5 measurements. RT is the total reaction-time (sec.); σ is the root-mean-square deviation of a single observation. The data in the column headed *Series A* are for the smaller of the two areas studied (diam. = 0.3 cm.); those in *Series B* are for an area which is approximately seven times as great as (and includes) the smaller area (diam. = 0.8 cm.). Gustatory reaction times to saline solutions vary inversely with an increase in area and hydrostatic pressure.

Pressure, in gm/cm²	A. H. H.		L. M. H.	
	Series *A*	Series *B*	Series *A*	Series *B*
	R.T. $\pm\sigma$, in *secs.*	R.T. $\pm\sigma$, in *secs.*	R.T. $\pm\sigma$, in *secs.*	R.T. $\pm\sigma$, in *secs.*
1	19.05±1.04	12.99±2.16	21.76±2.01	15.85±1.56
2	18.18±3.88	11.61±0.94	19.77±1.42	15.50±1.31
4	16.98±5.21	12.11±1.05	20.06±1.56	13.27±1.23
8	16.64±0.66	10.91±1.77	16.65±1.25	12.39±1.29
16	14.93±2.55	10.27±0.58	16.01±1.44	12.03±1.28

The taste-cells are lodged in buds located in the walls of papillæ which are surrounded by irregularly shaped canals, or ditches (**10**). After the tongue has been rinsed and thoroughly 'dried' with the blotting paper, about one-fifth to one-third of the total volume of these ditches is occupied by saliva and tap water.[3] Direct microscopic observation indicates that this residue is not evacuated even by the highest hydrostatic pressures employed.[4] It seems probable there-

[3] This estimate was made with the aid of a travelling microscope.

[4] An increase in the applied pressure leads to an increase in leakage at the edge of the cylinder in contact with the irregular surface of the tongue. The solution thus spreads to receptors which lie outside of the limits provided by the circumference of the cylinder; this may be seen when an illuminating microscope is focussed upon the liquid at the edge. If the tube is carefully and successfully maintained in a stable position with respect to the tongue, however, the spreading is so slight as to produce a negligible

fore that we are here concerned only with receptors which are lodged above the level occupied by this liquid mixture.

At a given temperature and concentration for the specified regions of the tongue, the *rate* at which the NaCl-solution enters the narrow canals above this level and thus penetrates to the surfaces of the available hair-cells will vary directly with the pressure exerted upon the solution. This mechanical relation is of especial significance. It reveals why an increase in mechanical pressure can here lead to an increase in the speed of producing a definite amount (the cell-threshold amount) of chemical effect at the surface of any single taste-cell.

The speed with which this chemical effect is produced at the surface of a single cell will vary directly with the opportunity for contact provided to the constituents of the stimulating solute and the reacting taste-cell substance. The opportunity for producing a critical number of contacts (and hence a definite amount of effect) within a given interval of time is enhanced by an increase in pressure under the conditions of the present experiment. By the same token the time required for the production of threshold effect must vary inversely with the applied pressure. Thus, solely from a theoretical consideration of the mechanics and kinetics of proximal stimulation, can it be shown that an increase in pressure should actually lead to decrease in the length of time required to produce a threshold response in a single taste-cell.

If, now, we were to find it admissable to assume that the excitation of a *single taste-cell* is a sufficient condition for the eventuation of the total neuromuscular response which subsequently stops the chronscope, we should then have a consistent explanation for the results presented in Table I. [The total gustatory reaction-time decreases as the pressure increases—since, on the average, the reaction-time of the most sensitive taste-cell decreases with an increase in pressure.

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effect (relative to the probable error of measurement) upon the final result. A leakage which can be detected with the naked eye, however, usually does exert a significant influence. In the present experiment, all trials which manifested leakages of this magnitude were rejected.

The total reaction-time decreases as the area is made to increase—since the probability of contacting a still more sensitive cell will vary directly with the size of the test-area.] The next step would be to draw a more strictly quantitive comparison: *i.e.*, to apply mathematically to our results the rules of mass-action which govern the velocity of ordinary chemical reactions. Such a program is very attractive from a scientific point of view. It is experimentally productive, it attempts theoretically to render a rational explanation of the obtained results, and it serves to guide the degree of rigor required for experimental controls.

Nevertheless, in spite of these very attractive features, the general notion seems to us wholly untenable. It is untenable because it rests on an assumption (vide supra) which in turn implies that the excitation of a single primary sense cell is enough ultimately to evoke the motor response in question. This assumption and its implication are contrary to experimental fact (**6**). The assumption is therefore not admissible, and must be rejected.

A more tenable hypothesis is that which correlates the *minimum perceptible* with the preefferent eventuation of a constant number of nervous impulses per unit of time in the central nervous system. This assumption is consonant with the psychological facts concerning the threshold as well as the facts of neurophysiology; it can accordingly be employed to serve as a common medium of exchange for the psychophysiological interpretation of both sets of facts.

The two facts established by the results of the present experiment, for instance, are readily accounted for by means of it in terms of well-established neurophysiological fact (**1**). Consider the curves drawn in Fig. 1. The reciprocal of the reaction-time measures the speed of the total response, and the $1/RT$ values have been used as ordinates. The functions show clearly that the speed of the response increases with an increase in the applied pressure and area for each observer.[5] By increasing the pressure, we have enhanced the

[5] A small constant error exists in all of these measurements, owing to the fact that a 'constant' interval of time is required for efferent nervous impulses to reach and to

opportunity for contact between the molecules of the solute and those on some of the surfaces of the primary taste-cells, thereby decreasing the time needed for the central eventuation

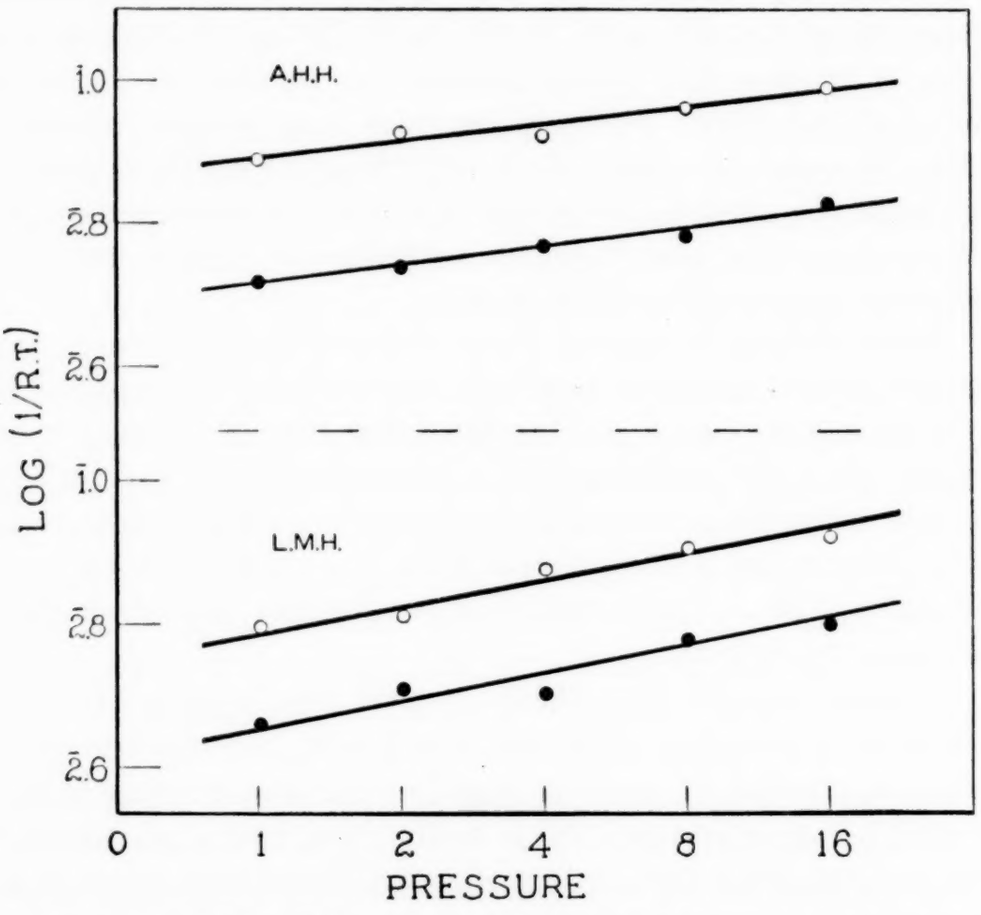

FIG. 1. Double-log grid showing speed of gustatory response as a function of hydrostatic pressure and amount of taste-cell substance for two observers. Concentration and temperature are parameters. For each observer, the speed of the reaction is an increasing function of the applied pressure. The open circles represent values obtained by stimulating an area on the tongue which was seven times as great as (and included) the area from which the values depicted by the shaded circles were secured. The speed of reaction also increases as the amount of taste-cell substance is made to increase. For theoretical significance, see text.

of a given number of gustatory nerve impulses per unit of time. By increasing the area, we have increased the number of excitable gustatory nerve fibers, thus (even if the sensory-cell thresholds were equally distributed) increasing the like-

discharge the muscle-fibers operating in the index-response employed. [The general procedure to be followed in attempting a correction is given by Crozier; *cf.* (3).] No correction has been attempted for the values shown in Fig. 1.

lihood of shortening the time required for producing the critical number of impulses per unit of time needed to evoke the observed motor-response.[6]

Summary.—The technique of the simple sensory reaction has been used to determine the speed of the gustatory response to NaCl-solutions. Concentration and temperature of the inciting solute were parameters; hydrostatic pressure and area of exposed sensory surface, variants. Data were secured for two areas and for five pressures from practiced subjects. The results demonstrate that the speed of the reaction is an increasing function (*a*) of the applied pressure and (*b*) of the area of the stimulated sensory surface. The mechanics and kinetics of proximal stimulation were considered; the notion that a single taste-cell may be a sufficient condition for the arousal of the threshold was rejected. Instead, a theoretical interpretation of the obtained functions was formulated in terms consonant with neurophysiological fact. The *minimum perceptible* for taste is taken to depend upon the eventuation of a constant number of nervous impulses per unit of time in the central nervous system.

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[6] 'Anatomical' elements (*e.g.*, excited nerve fibers) are of course also admissible as concerns the interpretation of such results. At present, however, we incline toward the use of the dynamic unit, or element (= the number of nervous impulses per unit of time); see Adrian (1).

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THE STRUCTURE OF SIMPLE COMPOSITIONS: THE RELATION OF SINGLE ELEMENT TO THE FIELD[1]

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It has long been recognized that the achievement of a satisfactory artistic composition, involving the disposition of objects within a given field, is a difficult task and one involving the consideration of the multiple relationships existing between the objects and the particular field in which they are displayed. While estheticians and critics have described in general terms the types of compositional arrangements, little attention has been paid from the psychological standpoint to an analysis of these complex relationships and the kinds of factors involved.

It is apparent from the outset that a composition, that is, a picture or a design, is a product of figures or elements on a field, either inclosed or open. A single element suspended in a field without a border would be the negation of a composition since it would not be in perceivable relations to any other elements or any bases for relationships. The presence of a boundary, creating an outer field and an inner one, in which the single figure is located, provides the possibility of relationships and the potentialities for satisfactory compositional arrangement. It would be an interesting problem to determine, with a single figure, at what distance a field border begins to function, and the object is perceived as related to it.

Disregarding for the present the complex types of com-

[1] This experiment was carried out at the University of California. I am indebted to Prof. Stephen C. Pepper, Department of Philosophy, for his generously given criticism and practical assistance in conducting the experiment, and to Prof. Warner Brown, Department of Psychology, for reading and criticizing the longer experimental report. Discussions with Mr. Glenn Wessels of Berkeley, an artist, about compositions lead to the experimentation and while the following differs in its theory from his views, I believe, I am indebted to them for their stimulation.

positional arrangements in which several figures are used and in which, in painting for example, third dimensional representation operates to make the field one of space rather than of area, we are concerned in the following experiment with the simplest type of composition: a single simple figure on a two dimensional field. The object of the experiment was to discover what positions the subjects would chose on the field for the placement of the single element and what reasons they would advance for those placements giving satisfactory compositions. The figure was a small black dot and the field a white rectangle.

A series of preliminary exploratory experiments with dots of various sizes and with square fields had shown that certain dot positions were preferred to others and that there seemed to be a considerable degree of agreement between the subjects as to the satisfactory positions of the dot in the field. It was decided to undertake a group experiment, the experimental conditions being altered to this end, to determine the places in the field in which the dot stood in satisfactory relationships to it, the extent of the agreement between the subjects, and the reasons advanced for such placements.

Procedure

The subjects were one hundred and ten men and women college students of junior and senior years, members of a class in esthetics. This group had received several lectures immediately preceding the experiment, on composition in painting, but no specific statements had been made concerning desirable types of compositions or any analysis made with such simple material as was used in the experiment.

The material given to each subject consisted of three blank white library filing cards, three by five inches in size, and a small circular dot one-quarter inch in diameter with smooth edge, cut with a punch from fairly stiff black cardboard. Each subject was given an envelope containing the dot and the three cards, into which they were returned on completion of the experiment.

When the material had been distributed, the experimenter gave the following instructions: "Within the envelope you have been given three rectangular cards and one black dot. That dot is precious; there is only one to be placed in a different spot on each card. Take one card out and find the best spot for the dot on it and mark the place with pencil or pen. The card is to be held with its long axis horizontal. Now take the second card and find another good place for the dot and mark that one. Likewise with the third. Now, write on the back of each card why you put the dot in that place, if you can. Write as much or as little as you want to. Return the cards to the envelope when you are finished."

The experiment took in all about twenty-five minutes.

Types of Compositions

Examination of the reasons advanced by the subjects for the placements in the various compositions they made reveals a great variety. Some refer to the things that the dot symbolized, some merely evaluate the compositions, while many give detailed statements of the reasons for the particular placements. Despite the variety of statements, it is possible to distinguish between them on the basis of their reference to the elements which enter into the construction of the composition. Considering these statements as descriptions of the factors which were considered in making the compositions, we can distinguish constructions involving only the properties of the dot and the rectangle from those involving extra-dot-and-rectangle factors as in representation or symbolization.

On this basis we distinguish between depictive or representative designs and formal designs, or those concerned with the picturing of some object or scene as against those concerned with the inter-relations of dot and field alone. An intermediate type of composition is that wherein the placement of the dot on the card suggested or recalled an object or relationship to the subject. A small group of subjects gave no reasons.

Since all subjects did not hold consistently to one type of compositions in their three constructions, the suggestive and depictive being mixed with the formal, we indicate below the number of subjects constructing the various types of compositions and the number of each type constructed.

A. Formal Compositions

As shown in Table I, the majority of compositions constructed were those in which, judging by the statements of the subjects creating them, the factors considered were solely the rectangle and the dot, and the achievement of some sort of relationship between them. The types of relations sought by the subjects in their designs were numerous and varied but they had one thing in common: the relation sought was one between the dot and the parts of the rectangle, whether

TABLE I

Types of Compos. Constructed	Number of Subjs.	% of Subjs.	Frequency of Composition Types				
			Formal	Depict.	Suggest.	No St.	Total
1—Formal only	83	75.5%	249				249
2—Depictive and Formal	2	1.8	2	4			6
3—Suggestive and Formal	19	17.2	23		30		53*
4—No Statements	6	5.5				18	18
Total Subjects	110	100.0%					
Total Compositions			274	4	30	18	329
% of Total Compositions			83.2%	2.1%	9.4%	5.4%	100%

* One composition omitted as placement not clear.

considerations of area, sides or distances from them, or the potentialities for the formation of figures. The composition was the result of such patterning and was not influenced by external demands for representation.

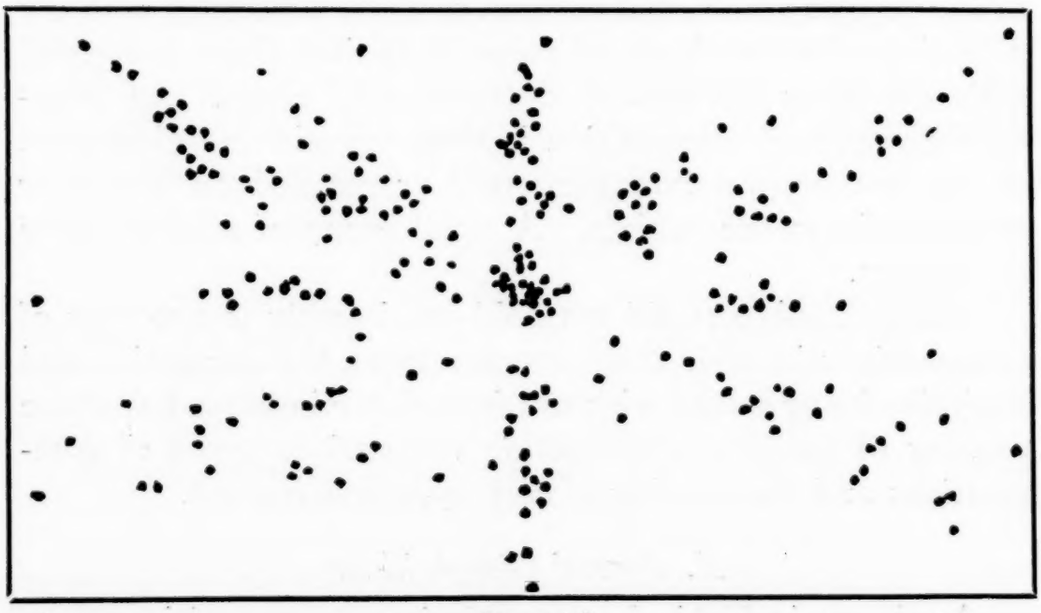

FIG. 1[1]

In Fig. 1 we present a record of the dot placements of the two hundred and forty-nine compositions of the subjects creating formal compositions only.

It is apparent from this figure that the positions chosen

[1] The record was obtained by superimposing the actual compositions on a card and recording the dot position by a pin prick at the mark made by the subject. They cannot be considered as highly accurate.

for the placement of the dot were in many cases very similar. A number of fairly well defined regions of the field stand out as areas of maximum placement while other regions were never or seldom used All parts of the field were apparently not equally suitable for satisfactory location of the dot. We find therefore, judging by the clustering of dot positions, that the subjects were in considerable agreement in many cases as to the locations in which the dot stood in a satisfactory relation to the field.[2]

A clustering of dot positions in the figure indicates of course that the compositions, whose placements they record, were practically identical or very similar. The homogeneous clustering of placements in the center and in the mid-regions of the horizontal and vertical lines from the center to the sides shows that a large number of compositions were constructed with dots at these five locations. The long clusters of placements reaching in from the corners toward the center along the diagonal zones in the upper quadrants indicate that many compositions were made with dot locations in these areas. Such agreement is not so clearly manifest in the lower quadrants, possibly due to the fewer number of compositions with dots in these regions. We find many similar compositions with placements in an inner region lying on the right and left sides of the upper vertical regions and close to the respective diagonal zones. The similarity of these compositions is shown most clearly by the clustering of dots in this region in the upper right corner where eleven compositions had almost identical placements. Such areas are again not clearly indicated in the lower corners.

Table II indicates the frequencies with which compositions occurred with dot locations in the same regions. Those classified as off-center were separated to distinguish them from the center compositions since the subjects stated in regard to them that their intention was to place the dot in a position close to the center but not at it; in all cases they fell close to the center cluster.

[2] The regions would appear more homogeneous if actual quarter inch dots were used in the figure.

TABLE II

FREQUENCIES WITH WHICH COMPOSITIONS WERE FORMED BY DOT PLACEMENT IN THE VARIOUS REGIONS

Region of Placement	Number and Frequency of Compositions				
Center		35	14.1%		14.1%
Horizontal axis					
Left	14		5.6		
Right	9	23	3.6	9.2	
Vertical axis					
Upper	25		10.0		
Lower	20	45	8.1	18.1	27.3
Corners					
Upper right					
Diagonal zone	20		8.1		
Inner zone	17	37	6.8	14.9	
Lower right		25		10.0	
Upper left					
Diagonal zone	31		12.4		
Inner zone	20	51	8.1	20.5	
Lower left		28		11.2	56.6
Off-center		5	2.0		2.0
Total compositions		249			100.0%

Reasons Advanced for Formal Composition Placement

Analysis of the reasons advanced by the subjects as explanations for the position of dots in the formal compositions reveals considerable variety. It is apparent that a classification cannot be highly accurate or do justice to the slight differences in meaning and probable intention. We have therefore merely classified them according to the general intention of the statement, grouping those together that mentioned similar factors, such as an interest in spatial relationships or a demand for balance or symmetry. In some instances apparently unique interests are found bearing no similarity to other reasons.

Table III indicates the frequencies with which the various kinds of reasons occurred, distributed according to the compositions to which they referred.

The most frequent basis for a formal placement, occurring with 18.0 percent of the compositions, was the interest in the addition of lines to the field. The dot was related by lines

TABLE III

FREQUENCIES WITH WHICH THE TYPES OF COMPOSITIONS, CLASSIFIED BY DOT PLACEMENT REGIONS, WERE BASED ON THE VARIOUS REASONS ADVANCED

Reasons for Placements	Center		Position of Dot								Corners								Tot.	Percent
			Up. Ver.		Low. Ver.		R. Hor.		L. Hor.		Up. R.		Low. R.		Up. L.		Low. L.			
1. Linear additions relating dot and field	9	26%	4	16%	7	35%	4	44%	5	36%	4	11%	5	20%	4	8%	2	7%	44	18.0%
2. Achievement of balance, symmetry	16	46	10	40	4	20	1	11	2	14	2	5	2	8	1	2	1	4	39	16.0
3. Rejection of balance, symmetry			1	4					2	14	7	19	3	12	13	25	6	21	32	13.1
4. Spatial relations between dot and field											6	16	5	20	13	25	5	18	29	11.0
5. 'Natural place' for dot	7	20									2	5							9	3.7
6. Relations to axis of field			3	12	1	5	2	22	1	7									7	2.9
7. Position on diagonal from corner											3	8	1	4	1	2	2	7	7	2.9
8. Feeling of weight or 'solidity'					2	10											4	14	6	2.5
9. Feeling of 'movement' from dot position									3	21							2	7	5	2.0
10. Feeling or 'radiation' from dot			2	8	1	5									1	2			4	1.6
11. Feeling of 'expanse' and 'depth'			1	4							2	5							3	1.2
12. Unique and unclassifiable	1	2	1	4	2	10			1	7	7	19	5	20	5	10	2	7	24	9.8
13. No reason advanced for placement	2	6	3	12			2	22			4	11	4	16	13	25	4	14	35	14.3
Total compos.	35	100%	25	100%	20	100%	9	100%	14	100%	37	100%	25	100%	51	100%	28	100%	244*	100.0%

* Five off-center compositions omitted.

to various parts of the rectangle, either for the sake of the linear pattern in itself, or for the areas of various sizes and shapes that such lines created. In the majority of cases lines were drawn to all four corners from the dot, but with some placements, only two lines were added, running to the corners nearest to the dot. In a few instances the horizontal and vertical lines were added but only when the dot was in the center or in one of the coördinate regions.

In only one composition the dot was not placed at the junction of the added lines. One subject placed the dot on the left horizontal with the statement: "The diagonal lines . . . run across the rectangle, and the dot was placed in (the) position that would be most interesting—in the most interesting triangle that was formed by these diagonal lines." The lines here form an important part of the whole composition as the relation of the dot to them and the area they created is the major interest.

The second most frequently advanced reason, occurring with 16.0 percent of the compositions, was a preference for a position giving a feeling of balance or symmetry. Most of these merely stated that balance was sought for or preferred. A few mentioned that the dot balanced the areas on each side of it or was in a symmetrical relation to the rectangle.

Definite statements that the subject placed the dot in a position that was not balanced or symmetrical were of third place frequency, occurring as a basis for 13.1 percent of the compositions. Several subjects mentioned a definite disliking for symmetrical relationships, and many statements were found such as the following: "I like a sense of off-balance," "Very interesting unbalance," and "Pleases me more than if it were in the center, balanced."

In fourth place frequency, with 11.0 percent, were statements indicating that the dot was placed in such positions as to create interesting spatial relations between it and the surrounding area. These were variously expressed and apparently indicate that a variety of factors were considered. Some subjects stated that the location was influenced by the consideration of the relations between the spaces its position

created on the field, as expressed in the comments "Leaves variety of spaces around the spot to keep interest alive" and "Makes the most interesting spacing of the areas." Other subjects expressed a feeling for the relation of the dot to the areas around it, as found in these statements: "The space left and below the dot balances the space right of it" and ". . . the rest of (the) card seems to balance the black spot as there is so much white opposite to it."

These four reasons comprise over half of the reasons given for formal placements. The remainder involve considerations that occurred with little frequency. Of these infrequent reasons, the statement that the dot was placed where it was since that was the 'natural place' for it occurred in connection with 3.7 percent of the compositions.

Of the less frequent bases for placements, occurring with equal frequency, 2.9 percent, were the feeling for the diagonals from the corners, or the relation the dot made to the sides in a position on a diagonal, and an interest in placing the dot where it would be on an 'axis' of the field, or give such a feeling.

In a small number of statements, 2.5 percent, the subjects indicated that they gained a feeling of satisfactory equilibrium from the location of the dot at the bottom of the card. We find expressions such as, "This is a solution which gives a feeling of solidity and weight with area of interest at the bottom" and "Is a comfortable solid resting place." Five statements, 2.0 percent, mentioned a feeling of 'movement' from the position of the dot. We find expressions such as, "The spot in this position would give me the feeling of movement in a horizontal line across the card. I have placed all three dots from a standpoint of design creating different movements" and "I like this because it has a definite feeling of motion right along the horizontal axis of the card." Four statements, 1.6 percent, mentioned that a 'radiation' from the dot determined its position, the nature of which radiation was not clearly expressed. One subject stated "I felt the need for radiation away from the dot in an upward direction." Three statements, 1.2 percent, mentioned a feeling of 'ex-

panse' or 'depth' that the dot gave with regard to the area of the field as in such statements: ". . . this gives a feeling of depth" and "High on center, gives a good feeling of expanse upward."

A number of statements, 9.8 percent, expressed unique reasons that could not be classified with the others, or were not clear. Thirty-five compositions, or 14.3 percent, were not accompanied by statements. Some subjects merely expressed their evaluation of the dot's position, whether satisfactory or not.

Relation of Reasons to Types of Formal Compositions

The formal compositions whose placement records are given in Fig. 1 have been found to fall into a number of rather similar kinds, having identical or very similar dot locations. When we analyze the various reasons given by the subjects for these placements we find that with some exceptions there exists a fairly definite correlation between the reasons advanced and the types of composition, classified by the location of their dots, to which they refer. If we divide the compositions into two major groups, those with dot placements in the coördinates or in the center, and those with locations in the corner regions, we find that with some exceptions the reasons advanced with greatest frequency concern chiefly one or the other of these two groups of compositions, and are hardly ever of major importance in both types.

The interest in linear additions to the dot and the field, the most frequent reason, occurs with some frequency as a basis for all types of placements. However it plays a larger part in placements on the center and coördinates generally and forms the most frequent basis for both horizontal region placements and for lower vertical coördinate placements. In corner placements it is the least important of the four most frequent reasons in all except the lower right corner, where it ranks in importance with interest in spatial relations.

The demand for balance or symmetry, second most important reason, is similar in general to the interest in linear additions in regard to the type of compositions to which it

refers. Although it too occurs in connection with placements in all regions, it is a major basis for center and coördinate region placements. Responsible for almost half of the center compositions, or 46 percent, it was frequently given as the basis for locations on the upper vertical region. Of somewhat less frequency with placements in the two horizontal coördinate regions, it is a minimum with dot placements in the corners.

These two types of reasons form the major bases for placements in the center and coördinate regions. The third and fourth most frequent reasons form the most important bases for placements in the other type of compositions, those with dot locations in the corner areas. The rejection of balance is found in conjunction with only one placement on the vertical coördinate, in the upper region, and found twice as a basis for left horizontal coördinate placements. With corner placements, however, it is the major cause for upper right, lower left, and upper left corner placements, and is of second place importance in lower right quadrant placements.

The interest in spatial relations is even more definitely connected with compositions with dots in the corners, as it never occurs as a basis for center or coördinate placements, and is of major frequency with regard to placements within the quadrants.

Of the reasons of minor importance, the interest in axial positions, as might be expected, was found only in conjunction with coördinate placements. Similarly the interest in diagonals is found only in connection with placements in the corner regions. The feeling of weight or solidity is found only as a basis for placements in the lower parts of the field, and movement is given as a reason for dot positions that occur only in the left half of the field.

It is interesting to note that unique and unclassifiable reasons occurred with relatively much greater frequency with regard to placements in the corners than with the coördinate type of placement. This is also true with regard to placements without reasons, which occurred with one-quarter of the upper left quadrant compositions. No reasons were

given on the average for 6 percent of the center and coördinate region placements and for 17 percent for the corner placements.

B. Depictive Compositions

There were two subjects each of whom created two compositions which, judging by the statements, were intended to depict or represent certain relations symbolic of objects or situations. One subject stated of her two compositions, "I particularly placed the circle here because when I see a circle I think of the sun and I particularly like to see the sun from such a view that the rays may be seen, not from the entire circle but rather from part of it only" and "Here again I am guided by the sun, but from a different view. I want to make the straight lines radiate out from a common center outward into space." The second subject considered the attractive power of the dot to draw the eye and placed it where it would be most effective if the field were an advertisement.

The locations of the dots in these four compositions were all in those regions discussed above in which the majority of formal placements occurred.

C. Suggestive Compositions

A number of subjects constructed compositions which they reported suggested things to them. We have separated these since it is impossible for us to know whether this suggestion was influential in determining the place of the dot and was thus an antecedent determiner of the composition, or whether the design was made in dependence on other factors, and the suggestion arose following its completion.

Thirty-three compositions were created of this type by nineteen subjects. This small number does not allow us to draw conclusions as to the degree of similarity between their dot locations and those of the formal type. Two differences however were notable: no placements occurred at all at the center or on the right coördinate, and almost all placements on the coördinates were much closer to the edge than those of the formal type.

Two types of suggestions were mentioned, those in which

the dot on the field suggested an object and those in which the arrangement suggested scenes. Twenty-two statements mentioned objects, among which were filing cards, envelopes, monogrammed stationary, flag, book cover, stamp on envelope, index on playing card, and seven others. Eleven statements mentioned that scenes were suggested among which were a moon over a landscape, a falling comet, a ball in the air, the sun with radiating rays, a fist striking a table.

The twenty-three formal compositions created by these subjects who mentioned that some of their compositions suggested various things to them were not enough to allow us to compare them with the larger formal group. Their placements however were all within the same regions as the formal types and did not reveal any tendencies to utilize other parts of the field.

D. Compositions without Reasons

Six subjects, or 5.5 percent of the whole group, constructed compositions without giving reasons for the placement of any compositions. The record of these placements does not reveal any striking differences from the record of the formal compositions described above.

Conclusions

1. Of the one hundred and ten subjects, each of whom created three compositions by placing a black dot on a rectangular field, 75.5 percent considered only the relationships between the dot and the field (formal type), 17.2 percent created compositions among which many suggested objects or scenes to them, 1.8 percent created compositions with some intention to represent or symbolize, while 5.5 percent gave no reasons for their placements.

2. Analysis of the positions in which the dots were placed in the formal type compositions reveals that certain regions of the field were much more frequently chosen for placements than others. The majority of compositions fell into a small number of different kinds each with identical or very similar dot positions.

3. A small number of formal compositions were constructed with dot placements in regions infrequently used, while considerable areas of the field were never used for dot placement.

4. Regions most frequently used for formal composition placements were the center, the middle regions of the vertical and horizontal coördinates from the center to the sides and diagonal zones in the corners. A number are found with dots in an inner region between the diagonals and the upper vertical region.

5. The regions in which the majority of formal placements occurred form a simple symmetrical structure within the field and related in a simple manner to it.

6. Of the four reasons most frequently advanced for formal composition placements, the areas or figures or pattern created by the addition of lines and the demand for balance were primarily reasons for placements in the center and in the coördinate regions, while the rejection of balance and interest in spatial relations between the dot and the field were primarily causes for placements within the corner areas. Similar interests therefore generally led to placements in the same or similar regions.

7. Compositions whose dot placements suggested objects or scenes to the subject differed from the formal compositions in having no placements in the center and more placements closer to the sides.

Significance for a Theory of Design and Composition

The significance of these experimental results for a psychological analysis of the 'laws' of composition lies in the fact that the subjects demonstrated a high degree of agreement in the positions they chose for the placement of the dot on the field. The majority of placements clustered closely together while large parts of the field were never used for dot placement. Such agreement indicates the factors determining the dot positions were common to all the subjects. The task of forming a composition is that of relating the dot to the field in a satisfactory and significant way. The agreement in

the placing of the dot reveals that such relations were appreciated in very much the same ways by the subjects.

Generally speaking it seems apparent that two sets of factors operate to determine the placement of the dot. One of these are the innate psychological factors governing the perception of relationships and patterns. Perception experiments, especially those motivated by Gestalt psychology, have given evidence of the importance of 'organization' in perception and the tendency toward the organization of perceived material into configurations. The other set of factors result from the experience of the subject with design and his consequent set or demand for generalized types of relationships. Demands such as those for balance or lack of balance would be included in this category. Both of these sets of factors operate in varying degrees to determine what positions will be seen as possible and satisfactory pattern-relationships and which among these will be chosen.

The approach to the goal of creating a composition, the consideration of the potentialities for compositional arrangement of the specific material on the field, here a dot on a rectangle, brings about the 'structuring' of the field, *i.e.*, the recognition and appreciation of positions that would make manifest relationships satisfactory from the standpoint of perceptual and acquired demands. We have disclosed the 'structure' resulting from the compositional arrangement of the dot and field of the specific size and shape used in the experiment. With other fields and elements with other characteristics other structures will result. Analysis of such structures resulting from arrangements of more complex material provides an objective approach to the determination of the factors governing the appreciation and creation of compositions.

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